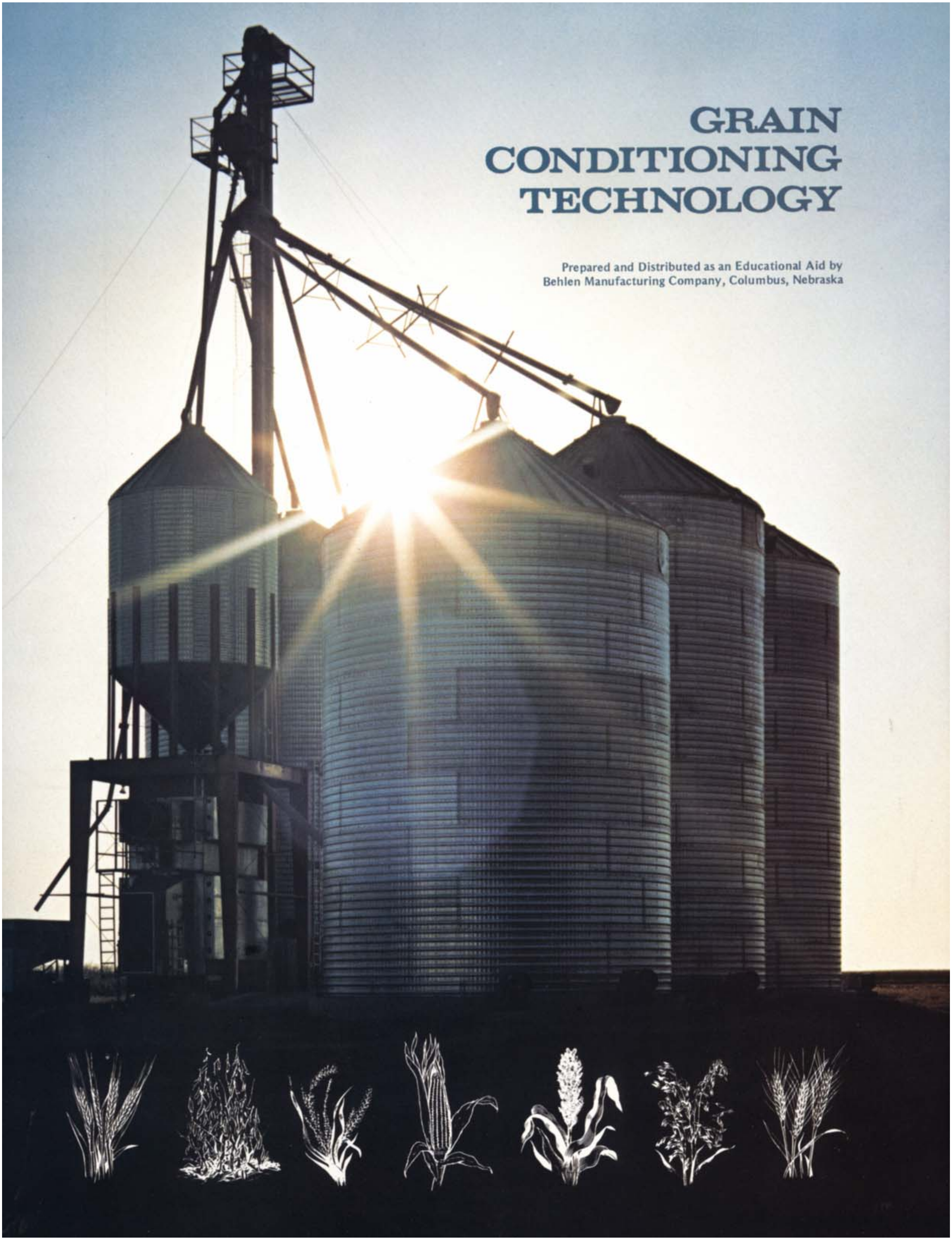
GRAIN CONDITIONING TECHNOLOGY

Prepared and Distributed as an Educational Aid by
Behlen Manufacturing Company, Columbus, Nebraska



FOREWORD

This manual was designed as an educational aid to acquaint persons interested in learning more about alternative methods of grain drying and conditioning that are used in the industry today.

The reader should recognize that due to varying temperatures and humidity conditions in different areas of the country, not all systems can be recommended for general application.

This manual should be used in that context. When specific design information is for specific applications — contact Behlen Manufacturing for additional information.

This manual is for comparisons and the material here-in should not be used for final design criterion.

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CHAPTER 1

Grain Drying

Why Dry?

Regardless of the crop you raise, as it matures there is a point where optimum harvest efficiency is reached (i.e., a point in grain moisture content when harvest can be conducted with the least field loss). For the midwest corn farmer, that point may be between 26% and 28%. Optimum moisture percentages for other crops are usually available from a State University.

Above or below the optimum level, losses occur. If the grain is too wet, loss is reflected in handling damage; too dry and field loss accelerates.

If corn, for example, is allowed to field dry, loss can be as high as 20% of the total crop by the time it reaches 16% moisture. After covering fixed costs in taxes, seed, fertilizer, equipment, chemicals, labor and other operational overhead, the grain left in the field could easily amount to 50% of the producer's net profit. The chart below illustrates the severity of loss as field drying progresses.

Field losses as harvesting is delayed (average from tests in Iowa, Illinois, Indiana, and Nebraska).

	Percent Loss		
	Oct.	Nov.	Dec.
Machine Loss	4.6	7.0	11.8
Total Loss	5.0	8.4	18.4

Agricultural Extension Service, University of Minnesota.

Anyone making a field-loss check after harvest becomes painfully aware of the profit drain when even a small percentage of the crop is left in the field.

Estimating Field Loss

Corn	– 2 kernels per square foot equal 1 bushel per acre loss.
Wheat	– 18 to 20 kernels per square foot equal 1 bushel per acre loss.
Soybeans	– 4 to 5 beans per square foot equal 1 bushel per acre loss.
Oats	– 10 kernels per square foot equal 1 bushel per acre loss.

Here the economies of proper harvest scheduling are evident, making a strong case for early harvest.

The drying decision is not always a matter of choice. This is particularly true in the northern climates with short growing seasons, or in high humidity areas of the world. Corn dries at about ¾% a day from the time it dents until it reaches about 25% moisture. It is normally unaffected by weather at this stage. However, below this point, weather is a major factor. Corn in the 20-25% range dries at an average ½% a day if weather is favorable. If high humidity conditions persists, it can take more than a month.In some wet seasons it may not dry at all, but remain at a high moisture content. This will be further explained in the chapter dealing with equilibrium conditions in drying.

For most cash grain producers, artifical drying is a sound approach to improving profit. The livestock producer has the alternative of holding an ensiled product, and he must weigh the economic advantages of each system; but as long as grain is stored, marketed and transported in a relatively low moisture condition, the only currently viable solution for the practical handling of grain in volume is found in artificial drying. In this given circumstance, therefore, the challenge before the producer and the industry is to maximize the efficiency of drying techniques. This booklet is dedicated to the objective of creating a better understanding of how grain dries and, thereby, gives investors information upon which a sound purchasing decision can be made.

CHAPTER 2

The Size of the Job

A heated air grain drying process accomplishes two things: a) it warms the kernel so that moisture migrates to the outside surface and b) it evaporates moisture from the kernel surface, thus lowering the water content of the grain mass.

Why is it important to understand this basic law of drying? The answer is simple. No conventional, heated air drying system can operate at an efficiency level beyond the heat of vaporization of water. Any claims to the contrary would be false and misleading.

Heat is measured in BTU's (British Thermal Units). A BTU is the amount of heat energy needed to raise one pound of water 1° F. The heat of vaporization of water is approximately 1,075 BTU's. Energy is also required for the process of osmosis, which transfers the water from inside the kernel to the exterior surface where it can be readily evaporated. The exact amount of energy needed for this process is not known at this writing, but is believed to be in the range of 150 to 300 BTU's per pound of water, depending upon the initial moisture content, type of grain and type of hybrid. On this basis, the total minimum energy requirement to remove one pound of water from grain, would be approximately 1300 BTU's. A 100% efficiency level, therefore, would be reached if the drying system used 1300 BTU's to evaporate one pound of water from the grain mass in 60° F. ambient weather conditions. It is not probable — at least within the foreseeable future — that the drying industry will achieve 100% efficiency, but conscientious companies will continue to point their development efforts toward maximizing the utilization of available energy.

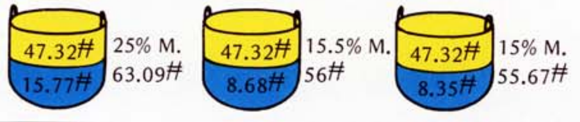
Heat energy can be drawn from a number of sources — solar, electrical, fossil fuel, natural gas or biomass. Perhaps, at some point in time, even geothermal sources might be considered. Appropriately, designers of drying systems will incorporate burners that employ the least expensive energy source, considering all capital requirements including the initial investment.

How much water needs to be removed in the drying process? It helps to understand the size of the task before determining the method. First, what constitutes a "bushel?" Let us use corn as an example.

A bushel is described as 56 pounds of 15.5% moisture corn. Dry matter content is 84.5% or 47.32 lbs., and water content is 15.5% or 8.68 lbs. A so called wet bushel would contain more water, but the same amount of dry matter. For example, a 25% moisture bushel would weight 63.09 pounds . . . 47.32 lbs. of dry matter and 15.77 pounds of water. See Chart "A" — page 3.

Moisture content is determined by dividing the weight of water present in the material by the total weight of the material.

WATER CONTENT EXAMPLE
WET & DRY CORN



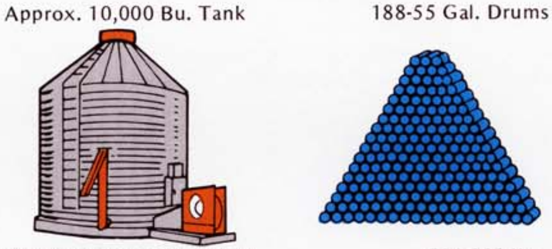
As you can see, 7.4 pounds of water must be removed per bushel to dry corn from 25% to 15% moisture.

15.77# – 8.35# = 7.42#

The diagram below offers a graphic example. If 10 points of moisture are removed from 10,000 bushels of corn (dry corn bushels), 9,275 gallons of water must be vaporized --- almost one gallon per bushel. It pays to select a system that is up to the job.

THE MASSIVE PROBLEM

Drying 10,000 Bushels to a Safe Storage Level



25% M. Original Wt. Equals . . . . 705,308 lbs.
15% M. Final Wt. Equals . . . . 622,330 lbs.
82,978 lbs.
Excess Water Equals . . 10,372 gal. or 188-55 gal. Drums

Determining Grain Shrink

When grain is dried, a "shrink" occurs. In other words, a weight loss results when water from within the kernel is evaporated.

It is important to remember when a given percentage of water is removed, weight is not reduced by the percentage. This is because dry matter content does not change.

For example, grain dried from 25% moisture to 15% moisture loses 11.8% of its weight, even though moisture content is decreased by only 10%.

To understand how much water must be removed from a given quantity of grain, follow this example:

Starting with 63,516.7# of 25.5% moisture shelled corn and drying to 15.5% moisture.

Step "A"

63,516.7# of 25.5% water = 16,196.7# water
63,516.7# of 74.5% dry matter = 47,320.0# dry matter

TOTAL 63,516.7# wet grain

Step "B"

When this quantity of corn is dried down to 15.5% moisture, the final weight is determined by the following formula.

$$\text{Wet\#} \times \frac{100 - \text{wet \%}}{100 - \text{dry\%}} = \text{dry \#}$$

$$63{,}516.7 \times \frac{100 - 25.5\%}{100 - 15.5\%} = 56{,}000\text{\# dry grain}$$

56,000 ÷ 56 lbs./bu. = 1,000 bu.

CHART "A"

DRYING SHRINK CHART FOR CORN

% Moisture	#/Bu.	# Shrink To Dry to 15.5% M.
10	52.57	– 3.43
11	53.16	– 2.84
12	53.77	– 2.23
13	54.39	– 1.61
14	55.02	– .98
15	55.67	– .33
15.5	56	0
16	56.33	.33
17	57.01	1.01
18	57.70	1.70
19	58.41	2.41
20	59.15	3.15
21	59.89	3.89
22	60.66	4.66
23	61.45	5.45
24	62.26	6.26
25	63.09	7.09
26	63.94	7.94
27	64.82	8.82
28	65.72	9.72
29	66.64	10.64
30	67.60	11.60
31	68.57	12.57
32	69.58	13.58
33	70.62	14.62
34	71.69	15.69
35	72.80	16.80

Step "C"

We can find how much water will be removed from each 1,000 bu. batch of grain.

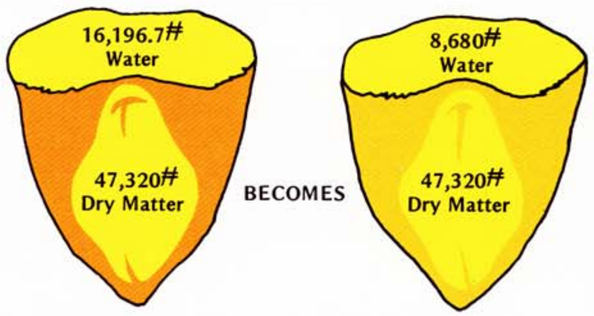
63,516.7# wet grain – 56,000# dry grain = 7,516.7#

Percentage of weight loss is found by dividing the weight of water removed by the original weight of the material.

7,516.7# ÷ 63,516.7 = 11.8% weight loss

Our conclusion then must be that an 11.8% shrink occurs when moisture content is reduced by 10%.

1,000 Bu. 25% Moisture Corn Dried to 15.5% Moisture



Take note of the fact that dry matter content remains constant, or so nearly constant the differences are difficult to measure.

56,000 lbs. final weight – 47,320 lbs. dry matter = final content of 8,680 lbs. water

8,680 ÷ 56,000 = 15.5% moisture

We can also use the formula in Step "B" to determine shrink in terms of bushels, if you choose to think of 56# as being a bushel regardless of moisture content.

$$\text{Wet Bu.} \times \frac{100 - \text{dry bu. \%}}{100 - \text{wet bu. \%}} = \text{Dry Bu.}$$

$$1134 \times \frac{100 - 25}{100 - 15} = 1{,}000 \text{ Bushels}$$

Through this formula, you find that 134 bu. (1134 – 1000 = 134) are lost out of 1134 wet bu., or 11.8% when 10 points of moisture are removed. No matter where drying takes place, in the field, in a farm dryer or at the commercial elevator this loss inevitably occurs.

CHAPTER 3

Two Ways to Dry

Methods of drying fall into two basic categories — equilibrium and non-equilibrium. It is helpful to understand these differences when you begin to evaluate the various types of dryers available.

Equilibrium System:
In-storage drying with natural air, or natural air with supplemental heat, is classified as an equilibrium system, i.e., a system in which the grain is allowed to fall into equilibrium with the air being forced through it. If the air is too dry, the grain will overdry. If the air is too wet or humid, the grain will not dry properly.

Non-Equilibrium System:
Drying with heated air in a column dryer or bin is classified as a non-equilibrium system. This is a system in which hot, dry air is forced through the grain. If the grain would be allowed to fall into equilibrium with the air, it would greatly overdry. In a non-equilibrium system, therefore, grain is removed from the air stream after it has reached a desirable moisture content. It is not allowed to reach "equilibrium" with the drying air.

Natural Air (Equilibrium) Drying

There exists in grain, and the air around it, a condition called "vapor pressure." If the grain has a low moisture content, a low vapor pressure exists. If it has a high moisture content, a high vapor pressure exists. When the high moisture grain is exposed to an atmosphere of lower vapor pressure, moisture tends to move from the high to the low. The converse is, of course, also true.

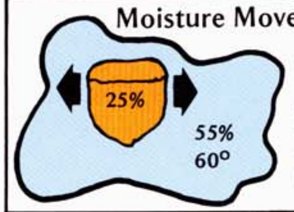
When, however, both the grain and the air around it have an equal vapor pressure, they are said to be in a state of "equilibrium," and no movement of moisture takes place.

Under condition "3", the grain and air are in "equilibrium." With this specific moisture and temperature condition, moisture content would never change, regardless of the amount of air that might be moved through it. This is the reason why natural air systems must be carefully managed to avoid underdrying or overdrying.

Chart "B" (page 6) quickly tells you what moisture level corn will reach when exposed to air at a given temperature and humidity. Check the following example. If the air temperature is 60° F. and relative humidity is 55%, grain will dry down to 12.1% moisture. If the temperature is 40° F. and humidity is 90%, grain will dry to 21.5% moisture. It then becomes obvious that certain climates will not permit dry-down without using supplemental heat to adjust the vapor pressure of the air stream and thereby lower the relative humidity.

The next step is to determine how much supplemental heat is required to achieve the proper temperature and humidity balance in the air stream.

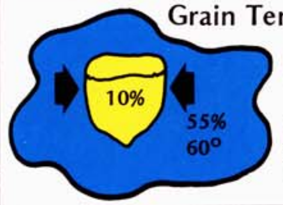
Moisture Moves Into Air Stream



Condition 1

Grain (corn) is 25% moisture. Air stream is 55% relative humidity; 60° ambient temperature. Moisture moves from grain to air stream.

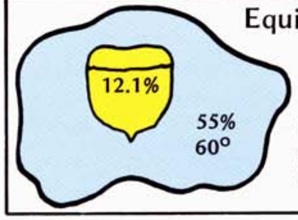
Grain Tends To Re-Wet



Condition 2

Grain (corn) is 10% moisture. Air stream is 55% relative humidity; 60° ambient temperature.

Equilibrium



Condition 3

Grain (corn) is 12.1% moisture. Air stream is 55% relative humidity; 60° ambient temperature.

The Effect of Heated Air on Relative Humidity

We have already determined from Chart "B", the point of equilibrium for a chosen level of moisture content. Armed with this knowledge, we can determine how much heat must be added to the air stream.

Chart "C" (page 6) provides the answer. Simply find the existing condition and follow a path parallel to the nearest line (moisture reduction curve) until you reach a point on the grid that provides the desired equilibrium. For example, if outside relative humidity is 90% and outside temperature is 50° F., equilibrium would be 20.5%. If we add 6° F. to the air stream, the temperature becomes 56° F. and the humidity drops to about 73%. Referring to Chart "B", we find that the point of equilibrium would be around 15%.

From a practical point of view, supplemental heat input cannot be adjusted with every climatic change. The humidistat on a supplemental heat system can normally be set to consider average conditions, turning on when relative humidity reaches, perhaps, 70%. On this basis, with a heat rise of approximately 6° F., final grain moisture should average between 14.5% and 15%.

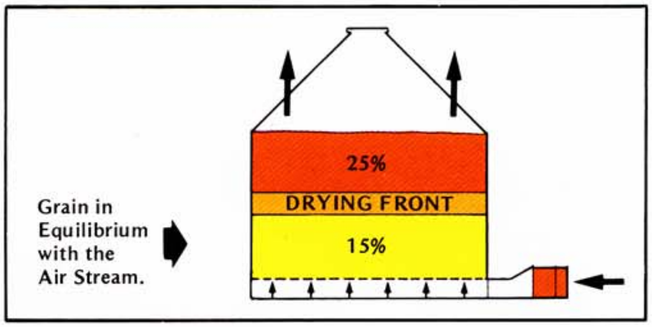
Rule of Thumb

Avoid the addition of too much heat. Excessive heat will not speed up the drying process, i.e., the rate at which the drying front moves up through the grain. It will, however, cause a second, lower drying front to form and, at the same time, increase the temperature of the exhaust air. This in turn, accelerates the growth of molds on the top of the grain layer.

A safe temperature rise would be 3° F. to 9° F. when the RH is over 70% depending upon the geographic location . . . 3° F. in dry areas, 9° F. in humid areas.

The Drying Front

In natural air drying, the drying front is a narrow transition zone between grain that has reached a point of equilibrium (below the front) and wet grain (above the front).



The rate at which the drying front moves up through the grain is determined by the amount of air flow. Moisture content, as previously explained, is determined by heat and humidity. A correctly designed in-storage system carefully balances all three elements of airflow, heat and humidity.

AIRFLOW MUST BE HIGH ENOUGH TO MOVE THE DRYING FRONT THROUGH THE TOP OF THE GRAIN BEFORE MOLD OCCURS.

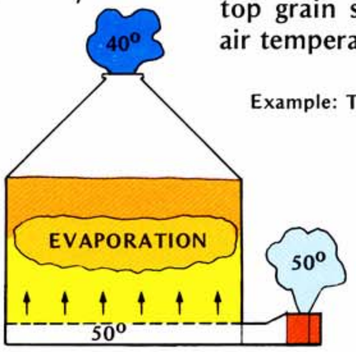
Chart "D" (page 10) shows the allowable storage time for shelled corn at various temperatures and moisture contents. The chart is read by first determining the exhaust air temperature, then finding the point at which the horizontal temperature line intersects the curved moisture percentage line. Following down from the point of intersection, you can then read allowable storage time in terms of days.

Example: 20% shelled corn, with an exhaust air temperature of 60° F., will remain in condition for approximately 25 days.

CAUTION: When determining the allowable holding time, try to establish an "average" that will consider both night and day temperature conditions. For example, if daytime temperatures are in the range of 70° F., with a 10° F., drop at night, estimates should be based on a 65° F. temperature.

Rule of Thumb

Grain temperature at the top of the bin will probably be 10° F. below the ambient or input temperature because of evaporative cooling. It is proper, therefore, to use the ingoing temperature less 10° F. to estimate grain temperature at the top grain surface and exhaust air temperature.



Example: Typical Fall Day = 60°F.
Night = 40°F.
Average = 50°F.
Exhaust = 40°F.
Approx.

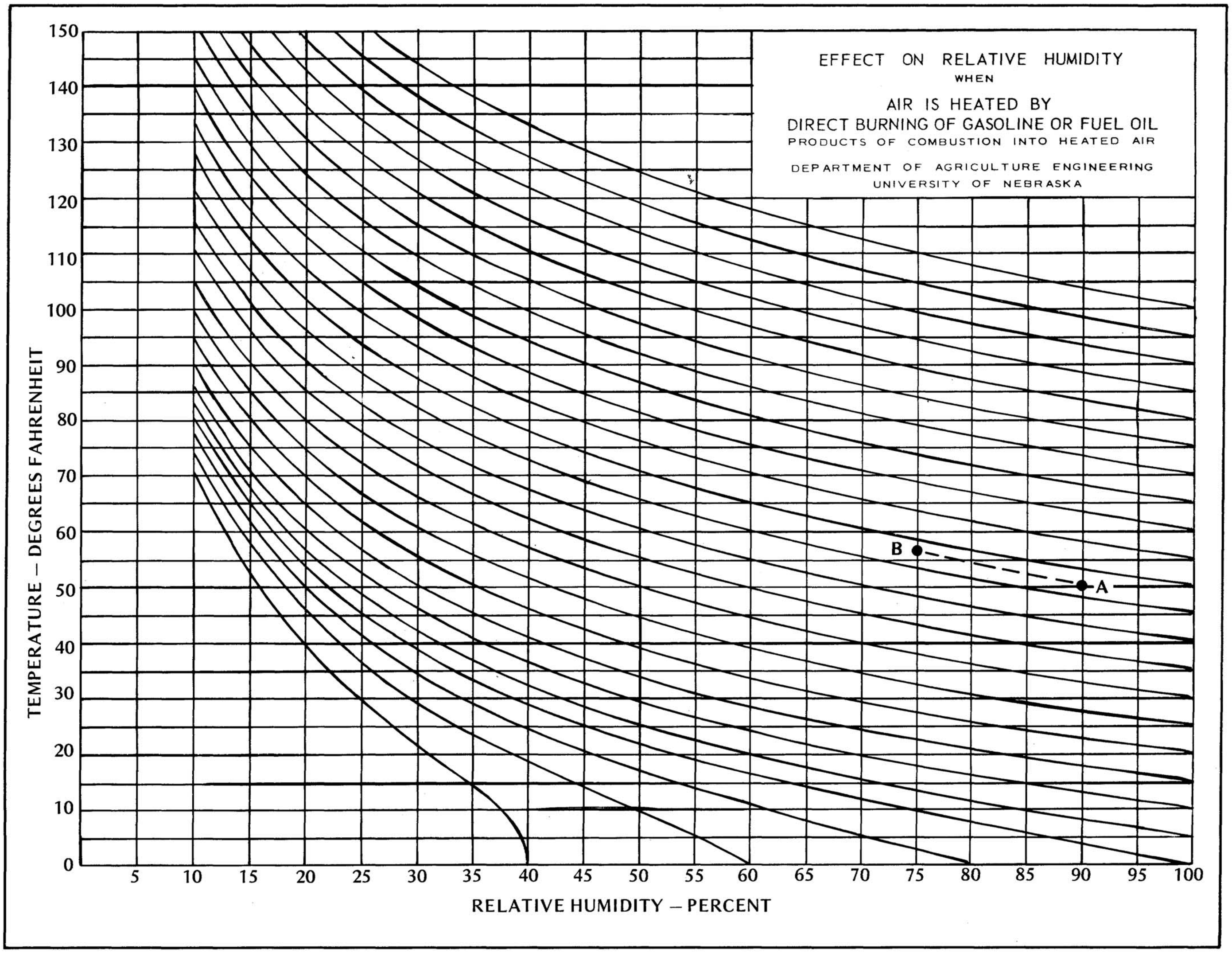
25% Corn can be held at 40°F. for a total of about 35 days before visible mold occurs.

CHART "B"

FINAL KERNEL MOISTURE CONTENT To be Expected in Shelled Corn When Dried by Forced Circulation of Air Having Various Temperatures and Humidities														
Air Temperature	Relative Humidity -- Percent													
	35	40	45	50	55	60	65	70	75	80	85	90	95	100
20°	11.2	11.7	12.7	13.7	14.5	15.1	16.2	17.1	18.0	19.6	21.2	23.5	25.8	29.1
30°	10.8	11.3	12.2	13.1	13.9	14.6	15.5	16.4	17.4	18.7	20.2	22.5	25.0	28.3
40°	10.5	11.0	11.7	12.5	13.3	14.0	14.8	15.5	16.6	17.8	19.4	21.5	24.2	27.5
50°	10.1	10.6	11.3	12.0	12.7	13.3	14.1	14.8	15.8	16.9	18.6	20.5	23.4	26.7
60°	9.7	10.2	10.9	11.6	12.1	12.7	13.4	14.2	15.0	16.0	17.8	19.5	22.6	25.9
70°	9.0	9.7	10.4	11.1	11.5	12.0	12.8	13.5	14.5	15.4	16.8	18.5	21.3	24.5
80°	8.3	9.1	9.8	10.5	10.8	11.2	12.1	13.0	13.9	14.8	15.8	17.4	20.0	22.8

*Data for these figures based on computations by G. M. Petersen, Associate Professor Agricultural Engineering Division, University of Nebraska, Lincoln, Nebraska.

CHART "C"



CHAPTER 4

Natural Air Drying

How long will it take?

In the foregoing chapter, we found the length of time that grain can be held before mold or spoilage begins. The next question, then, concerns the rate of drying. Will the drying front move to the top of the grain mass within the allowable time limit?

We start, first, by deciding what the airflow must be. If your climate is favorable for natural air drying, 1.5 cfm per bushel may be satisfactory. In warm, southern climates, 2.5 cfm per bushel may not even be adequate. For this example, we will select 1.5 cfm per bushel.

How much water will be removed each hour?

Assume that 10,000 bushels of grain are to be dried from 25% to 15% moisture. Then use this formula:

Bu. x cfm per Bu. x 1.1 (a constant) x Degree Temp. Drop ÷ BTU's to remove 1 lb. of water = lbs. water per hr. removed.

NOTE: Temperature drop is defined as the temperature difference between input air and exhaust air -- usually 10° F. when drying 25% corn, as explained in the previous chapter.

$$\frac{10{,}000 \times 1.5 \times 1.1 \times 10}{1075} = 153.48$$

Now that you know how much water will be removed each hour (153.48 lbs.), the drying time can be found. In Chapter II, The Size Of The Job, you found how to calculate the amount of water to be removed from a given quantity of grain at a given moisture content to reach a 15.5% storage level. In that calculation, 7,516.7 lbs. of water were removed from 1,000 bushels of corn. If the drying bin contains 10,000 bushels, 75,167 lbs. of water would have to be removed.

$$10 \times 7516.7 = 75{,}167$$

Now we have the answer.

(75,167 lbs. of water ÷ 153.48 lbs. per hr.) ÷ 24 hrs. per day = 20.4 days

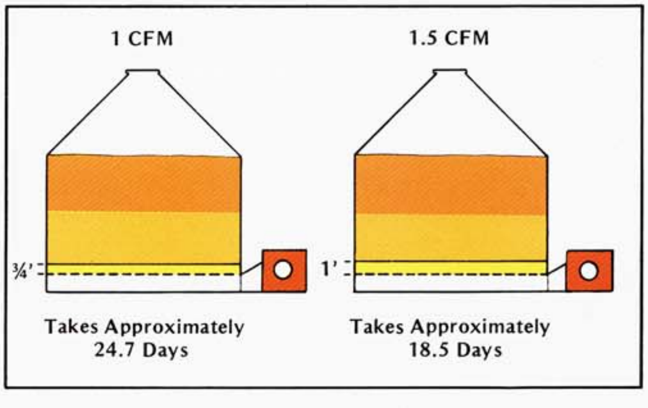
We now know that it will take approximately 20.4 days to dry the 10,000 bushels of 25% grain in the bin. A quick study of Chart "D"(page 10) will tell us if our natural air system, with 1.5 cfm airflow, will be adequate for the job.

Rule of Thumb

With an airflow of 1 cfm/bu., a drying front will progress from the bottom of the bin to the top at the rate of about ¾ ft. per day.

With an airflow of 1½ cfm/bu., the rate will be about 1 ft. per day.

CAUTION: A natural air drying system should not be used with grain over 25% moisture unless progressive, shallow layer drying is planned. Regardless of moisture content, check the allowable storage time (Chart "D", page 10) to be safe.



Non-Equilibrium Drying Systems

A non-equilibrium drying system is one in which high-air temperature and resulting low, relative humidity would, without timely removal of the grain, cause the grain to overdry. Non-equilibrium systems may take many forms.

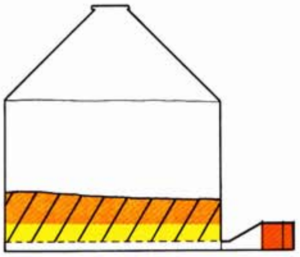
1. In-Bin Shallow Batch Dryers.

In the Shallow Batch System, a layer of grain up to 3½' deep, is placed in the bin, dried overnight with continuous heat, then cooled and moved into a different storage unit. This works well for operators who harvest at a moderate rate, fill more than one bin, and finally use the drying bin for storage; drying the last binful by utilizing the equilibrium system.

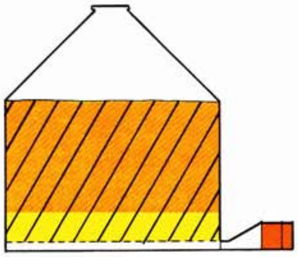
Rule of Thumb

Use about 20 cfm/bu. air-flow rate and about 120° F. operating temperature for best results.

The efficiency range of a shallow batch system is approximately 2000 BTU/lb. of water removed, drying from 25% to 15% moisture.



SHALLOW BATCH



DEEP BATCH

An example of time required to dry overnight is as follows: Assume a 3' depth in a 30' dia. bin, drying from 25% moisture down to 15% moisture.

- A 3 ft. layer will hold 1,696 bu. of dry grain.
- 7.4 lbs. water/bu. x 1,696 bu. = 12,550 lbs. water to be removed.
- Airflow = 20 CFM/Bu. x 1696 Bu. = 33,920 CFM, or 47.9 CFM/Sq. Ft. of floor.
- 33,920 CFM x 1.1 x 60° F. (Heat Rise From 60° F. ambient to 120° F. operating temp.) = 2,238,720 drying BTU's/Hr.
- 12,550 lbs. water x 2,000 BTU's/lb. = 25,100,000 BTU needed.
- 25,100,000 ÷ 2,238,720 = 11.2 hrs. heat cycle needed to dry from 25% to 15%.

2. In-Bin Deep Batch Dryers.

The Deep Batch System requires either a stirring device or grain recirculating device. Without this type of equipment, serious overdrying could occur at the bottom of the bin. There are pros and cons to the question of stirring grain during drying.

In certain arid climates, temperature and humidity conditions will not permit natural air drying without overdrying. In effect, deep batch drying with natural air then becomes a non-equilibrium operation.

This situation, in order to be workable, requires that the grain be stirred (or recirculated) on an intermittent basis, mixing the grain before it becomes overdried at the bottom. Since, in this instance, solar energy is not a cost item, the loss of energy through stirring is not a matter of concern and the system works well. The pitfall lies in stirring grain and using artificial heat to create a deep batch dryer. In this instance, stirring becomes quite inefficient.

Here is what happens. The action of the stirring auger tends to loosen a column of grain around the auger. This, in turn, creates an air column or "air leak." The volume of air moving through this area greatly increases, while static pressure beneath the dyring floor decreases, and heated air is exhausted at the auger points without being fully saturated (100% RH). This, of course, leads to a loss of heat energy and increased operating cost.

A recirculating system, although more expensive, does solve the problem of air escape by moving dried grain from the bottom, up through an enclosed auger, to be redistributed at the top of the mass. Heat, however, will still be exhausted because the warm grain has been brought to the surface, and the system will remain somewhat inefficient.

3. In-Bin Continuous Dryers.

This variation of the previously described recirculating system delivers hot grain from the bottom of the bin directly into a separate cooling bin. It is considered to be a more practical use of the bottom unloading concept because of increased versatility, and because large volumes of grain can be processed through the system. Also, heat efficiency is excellent --- approximately 1400 BTU's per lb. of water removed. Because of the relatively slow cooling of the grain in storage, most of the BTU's contained by the warm grain when transferred from the drying bin are not lost, but are utilized to remove approximately 1.5% moisture during the slow cooling cycle in the storage structure.

4. Portable Batch Dryer.

The portable batch dryer first gained popularity as a versatile unit that could be easily transported from field to field and farm to farm, making it ideal for custom drying operations. The portable batch system, both manual and automatic, has gradually given way to more sophisticated continuous systems, but it continues to hold a place on the American farm.

Batch dryer efficiency can be greatly increased by using it as a "first pass" dryer, i.e. drying grain down to approximately 18% moisture. At this point, the exhaust air is still fairly saturated and exhaust heat losses are minimal. The grain is then moved into a storage bin where it is dried down to a proper storage level using natural air.

5. Continuous-Flow Dryers.

Continuous dryers are available in a variety of shapes and sizes, including small portable types and tall column models. Airflow may be either cross-current (across the column of grain) or concurrent (moving in the same direction as the grain column).

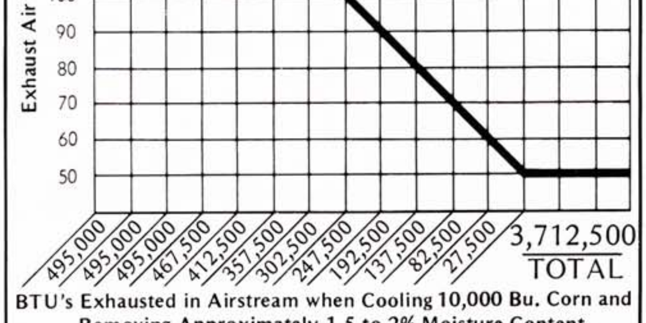
In this energy conscious age, heat reclaiming devices are now being attached to continuous dryers, resulting in substantial energy savings.

Capacity and automation are the strong selling points of the continuous system. Sizes and types, however, range from relatively small, portable models to large, column dryers used on very large farms or in commercial operations.

6. Add-On Systems.

Add-On systems can be utilized in two forms -- Dryeration and Cooleration (combination drying). Both systems combine artificial dryers (Batch, Continuous or Bottom Unloading) with a grain bin for further drying and cooling.

Dryeration



TYPICAL DRYERATION COOLING CYCLE USING ½ CFM/BU. TO COOL 10,000 BU. CORN FROM 140° TO AN AMBIENT TEMPERATURE OF 50°F.

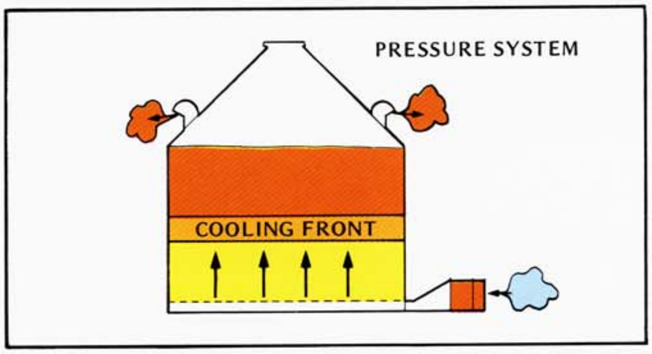
BTU's Exhausted in Airstream when Cooling 10,000 Bu. Corn and Removing Approximately 1.5 to 2% Moisture Content.

Dryeration consists of taking hot grain from the dryer at approximately 1.5 points above storage moisture, and slowly cooling in a bin -- using the residual heat in the grain to remove the final 1.5 points of moisture.

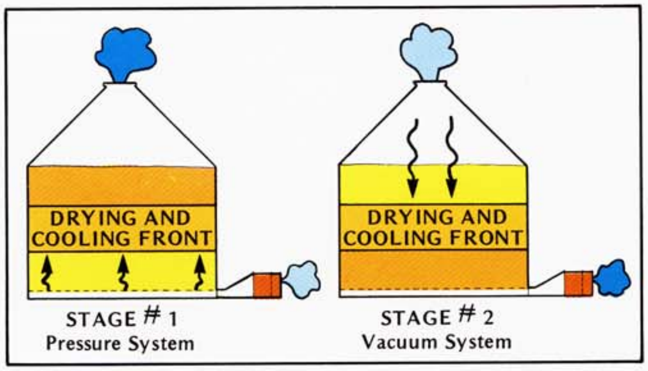
The original concept called for an interim cooling unit, i.e. a bin used for batch cooling, with the grain then transferred again into final storage. Over the years, variations of this concept have been introduced.

Today, most operators do not move grain from the cooling bin, but rather cool the grain in the storage unit. Cooling may be accomplished in two different ways using an airflow of 1/10 to 1/2 cfm per bu.

With a continuous pressure system, air is "pushed" up through the grain. A reversed or "vacuum" system would cause hot air to be drawn over the fan, eventually resulting in fan failure. The pressure system will, in some cases, cause condensation to form on the roof. This can be minimized by using power vents which draw in outside air which, in turn, expands to carry off the excess moisture. Outside air also combines with the grain exhaust air, lowering temperature to the point where power vent motors are not affected by heat.



Another system utilizes a reversible fan and has been tried with a good degree of success. In this method two cooling stages are used. A pressure system (1). is employed until the bin is approximately half full during cool weather conditions. Temporary condensation may form on the roof, but should not present a problem. The fan is then reversed to create a vacuum system. (2). Because the bottom layer of grain has been cooled, it then serves to cool air drawn from the hot upper layer of grain. In this way, no damage results to the fan, and condensation is eliminated on the bin roof. All of the grain eventually cools to ambient temperature.



Cooleration

Cooleration, or combination drying, offers the best of two worlds -- the speed of artificial drying and the economy of natural air.

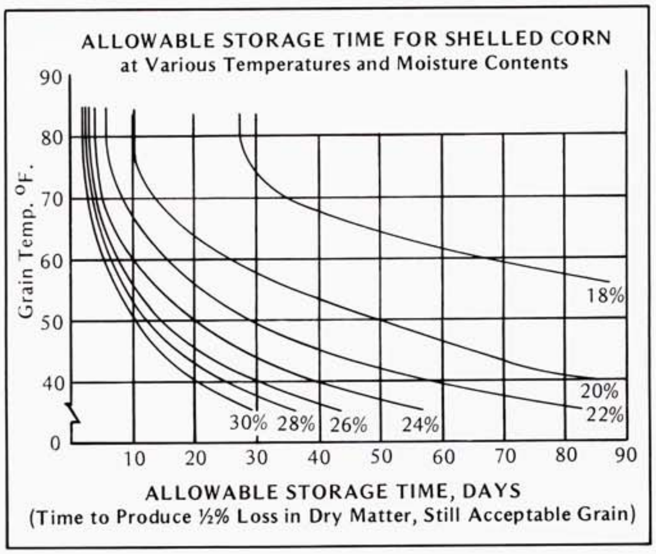
The system operates in this manner:

Grain is dried to approximately 18% moisture in a continuous or batch dryer. It is moved to a drying bin where it is cooled using the dryeration process -- in this instance, the only difference being that the fan used with the system should produce 1 CFM to 1.5 CFM per bushel.

When the grain is cooled, a natural air (equilibrium) drying process can begin, with the drying front progressing until the entire contents of the bin have reached a safe storage level.

This is an excellent way to utilize older drying equipment which is not — or cannot be — equipped with an energy-saving enclosure.

CHART "D"



CHAPTER 5

Equipment for In-Bin Drying

Understanding "static pressure" is the key to understanding fan performance. Static pressure is the pressure against which the fan must operate to force the air through the grain. It is measured in inches of water column with a gauge called a monometer. A monometer is simply a plastic "U" tube with a scale marked off in inches. The "U" tube is filled to the zero line with water (a special weight, non-freezing oil can also be used). One side of the "U" tube is connected to the plenum chamber underneath the drying floor and the other side of the "U" tube is vented to the atmosphere. When the drying fan is energized, a pressure is created which forces the water in one half of the tube up and the other half down. The difference between the two resultant water levels, measured in inches, is the static pressure. For example, if one side went up two inches and the other side down two inches, the static pressure would be four inches.

You can purchase a "monometer" from your dealer or make a simple unit from a plastic tube.

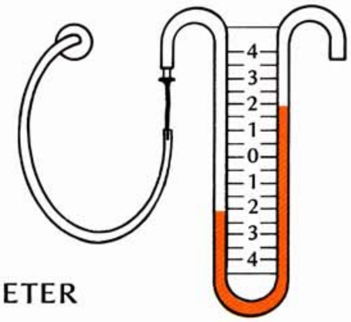
a) Mount plastic tubing (¼" to ½") on a board according to diagram.

b) Place a mark on the tube at approximately the center. This will be considered the "zero" point.

c) Mark the tube in one inch increments above and below the "zero" point.

d) Fill with water (you may wish to add a coloring agent) to point zero . . . or use a special monometer oil which has the same density as water, but will not freeze. Oil should be available from a local dryer dealer).

e) Extend the plastic tube and tap into the plenum beneath the drying floor.



MONOMETER

Some fans work better under a given static pressure than others. It is important to know why before making a buying decision.

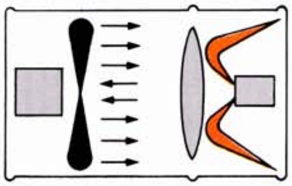
Two types of fans are used for in-bin drying . . . axial and centrifugal. Each has characteristics that make it suitable for specific jobs.

The Axial Fan

The axial fan is used primarily in situations where static pressure requirements are relatively low and airflow requirements are high. This occurs most frequently in smaller bins or shallow layer drying.

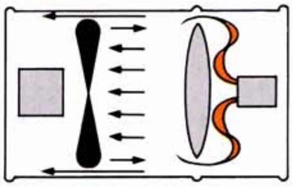
Under normal operating conditions, Diagram "1", at allowable static pressures, the tip of the blade pushes air forward, through the burner. A tendency exists for some air to leak back at the center of rotation where the blade speed is slower. Large hubs are frequently used in fan design to minimize backflow.

DIAGRAM 1



Normal
Operating
Conditions

DIAGRAM 2



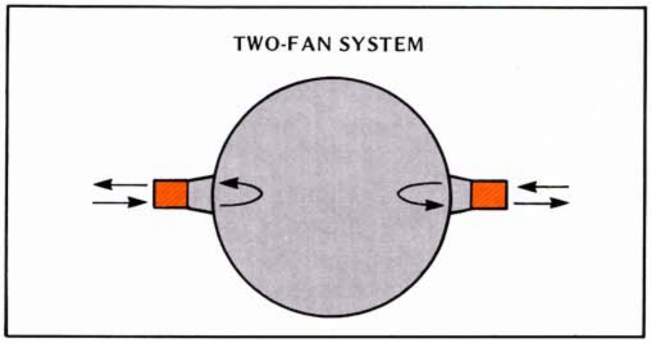
Excessive
Static Pressure
Conditions

When an attempt is made to operate an axial fan under excessive static pressure conditions, Diagram "2", failure will occur. Air begins to leak back along the length of the blade -- even at the tip. This, in turn, draws the burner flame back over the fan and motor. In the event a burner is being used, damaged components such as ignition wires will cause malfunction of the unit. Even if a burner is not being used, when only a fan is subjected to these same conditions, the fan motor may be severely damaged due to excessive heating.

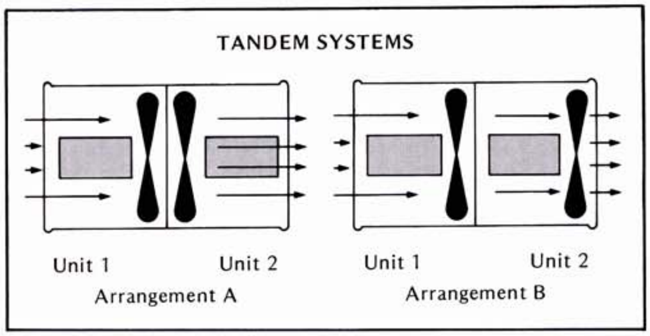
Fans can be used in tandem to increase airflow and static pressure performance capability. Do not confuse a tandem installation with two fans installed separately. The results are entirely different.

If the intention is to increase airflow and thereby speed drying with a second, separately located fan, the expected results may not materialize.

The reason is found in the build-up of static pressure. If the first fan is already near its maximum static performance level, the second fan will cause failure in both units. The grain will not dry faster and the operation becomes highly inefficient. Separate fans work well only when the static pressure caused by both fans does not exceed that of a single fan capability.


TWO-FAN SYSTEM

A tandem arrangement will not only increase airflow, but it also substantially improves performance, nearly doubling static pressure capability, thus allowing grain to be efficiently dried in a deeper column.

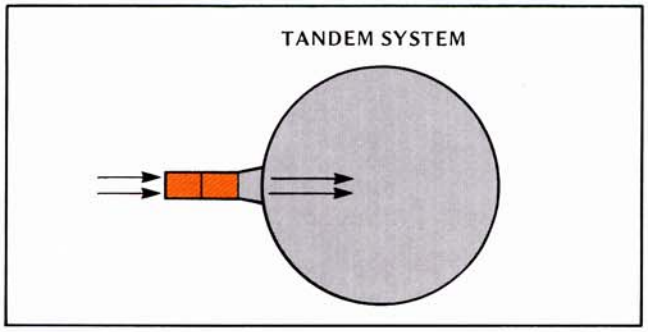

TANDEM SYSTEMS

It is best to arrange tandem fans in a push-pull configuration. In this manner, air movement cools both motors. Conversely, if both fans are pulling, air may have a tendency to channel and by-pass the second unit.

In the tandem system, the fan blade and polarity of the motor on unit 2 may be reversed.

CAUTION: Doubling the static pressure capability does not double the air flow. Air flow will increase but not double. To double airflow in any given circumstance, H.P. must be increased approx. four times.

Performance of tandem arrangements is shown in Charts "E" and "F" (page 14).


TANDEM SYSTEM

The Centrifugal Fan

The centrifugal fan finds application where performance under high static pressure is required. An important thing to remember about centrifugal fan design is that the tip speed of the blade determines static pressure capability. Smaller diameter fans of a given H.P. will produce a greater volume of air, but will "peak out" sooner.

Rule of Thumb

As the static pressure capability increases, the air volume per horsepower decreases.

In selecting the right centrifugal fan, it is always important to keep static pressure capability in mind. Air volume consideration alone is not enough.

Selecting the Right Fan

Depth and type of grain directly affect static pressure. Once the static pressure to produce a desired airflow is known, fans can be properly selected. Static pressure charts become easy to understand, by following this example:

1. Determine how much airflow will be needed when the bin is full. Use the information shown in Chapter IV for this purpose.

Rule of Thumb

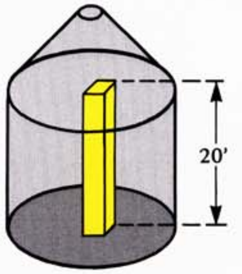
If grain is harvested at a relatively high moisture content and placed directly in a drying tank, an airflow between 1.25 cfm/bu. and 1.50 cfm/bu. is recommended.

If combination drying is used, with 18-20% grain placed in the tank, 1.0 cfm/bu. should be adequate. Less airflow is acceptable in this case because the reduction of moisture by rapid heated air drying extends the allowable holding time.

Assume, for this example, that we are drying in a 27' diameter bin with a 20' sidewall (a 10,000 bu. bin), and our airflow requirement is 1.5 cfm/bu.

2. The next step is to find the airflow requirement for a column of grain that is one foot square and 20' high. To do so, use this simple formula:

   1 sq. ft. x 20' high x .8 bu./cubic ft. = 16 bu.



   And so we find that an airflow of 1.5 cfm/bu., times 16 bushels, will give the air-flow requirement for each square foot of floor area.

   16 bushels x 1.5 cfm = 24 cfm/sq. ft.

   If the bin is 27' in diameter, the total air-flow requirement would be 13,741 cfm.

   Radius x radius x Pi = sq. ft. of floor space
   13.5 x 13.5 x 3.1416 = 572.566
   572.5566 x 24 cfm/sq. ft. = 13,741/cfm

3. Refer now to the Shedd Chart "H" (page 16).

   If your crop, for example, is shelled corn, follow a line from the left side, at the point of 24 cfm/sq. ft. until it intersects the diagonal line for shelled corn. At that point, reading to the bottom of the chart, we find that a static pressure drop (inches of water) between .2 and .3 inches occurs for each foot of grain depth. Using .24 inches as an average, we find that 4.8 inches of static pressure must be developed beneath a 20' column of grain to achieve the desired airflow.

   .24" x 20 = 4.8" static pressure

   CAUTION: When Shedd's Chart was developed, research was conducted using clean, dry corn. To consider actual field conditions, however, the chart should be adjusted to compensate for fines in the grain and/or wet grain. For this purpose, a factor 1.3 is used.

   1.3 x 4.8" static pressure = 6.24" static pressure needed.

   If you are drying corn, Chart "I" (page 21) makes this adjustment for you. Data for other grain and seeds can be taken with confidence from Chart "G" (page 15).

4. Conclusion: The fan you select should be able to operate at 6.24" of static pressure under a 20' column of shelled corn. The air-flow requirement in a 27' diameter bin would be 13,741 cfm.

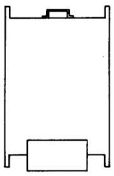
   Armed with this information, selection of the appropriate fan can now be made.

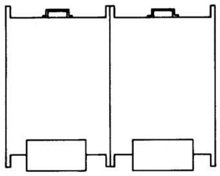
   In the foregoing exercise, we found that a fan would be needed that would produce nearly 14,000 cfm under 6.24" of static pressure. Referring to Chart "J" (page 21), we find that the fan closest to meeting performance requirement would be a 27" diameter, 20 H.P. centrifugal unit.

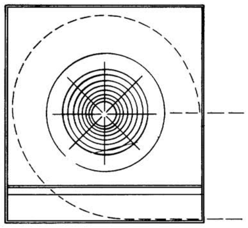
   Charts "E" & "F" (page 14) provide greater detail for the selection of axial fans in single and tandem arrangements.

BEHLEN FAN TYPE COMPARISON

CHART "E"

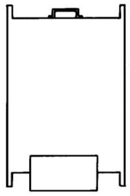


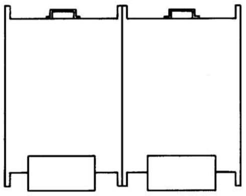


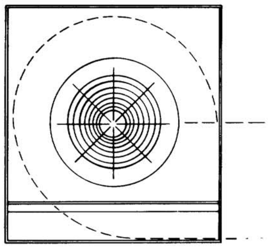


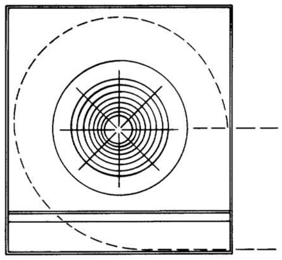
S.P.	ONE - 5 HP 24" AXIAL Axial CFM (Single)	TWO - 5 HP 24" AXIAL Axial CFM (Tandem Double)	ONE - 10 HP 28" CENTRIFUGAL Centrifugal CFM
1	9300	11,100	12600
2	7102	9,300	11800
3	4569	8,200	10800
4	2518	7,102	9800
5		5,685	8800
6		4,569	7800
7		3,517	6600
8		2,518	4900

CHART "F"









S.P.	BEHLEN ONE - 10/13 HP 30" AXIAL FAN CFM	BEHLEN TWO - 10/13 HP 30" AXIAL FAN Tandem CFM	TYPICAL ONE - 25 HP 30" CENTRIFUGAL	TYPICAL ONE - 25 HP 33" CENTRIFUGAL
1	23,600	24,400	19,875	16,300
2	21,500	23,600	18,950	15,700
3	18,300	22,700	18,050	15,300
4	13,800	21,500	17,250	14,800
5	8,800	20,100	16,550	14,300
6	6,100	18,300	15,650	13,650
7	2,600	16,200	14,800	13,150
8		13,800	13,800	12,450
9		10,000	12,650	11,850
10		8,800		11,050
11		7,500		10,150
12		6,100		
13		4,400		
14		2,600		

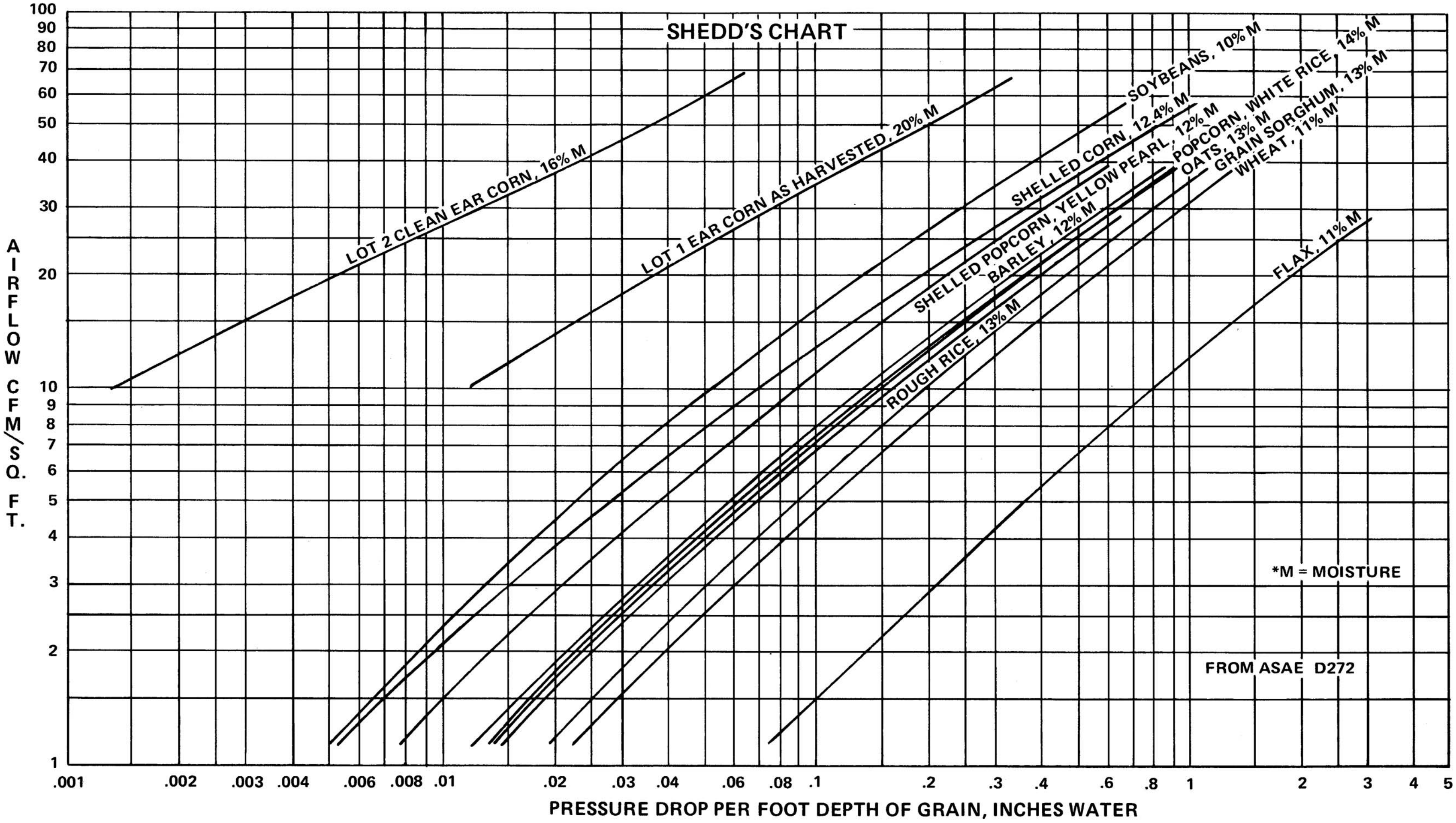
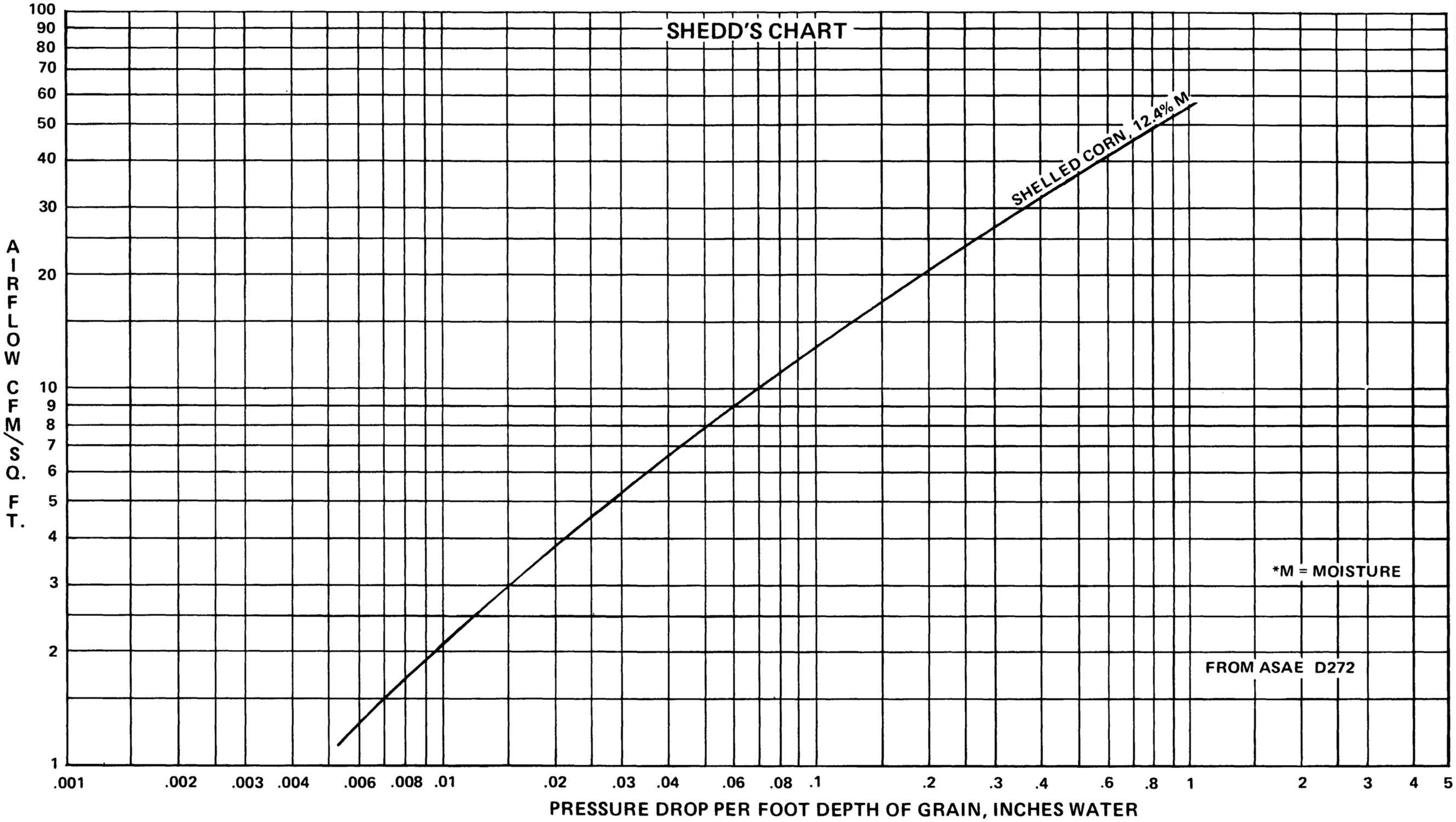


CHART "G"

CALCULATIONS	Example
1. Assume Grain Column 1 ft. square.	1Ft.^{2}
2. Determine Grain Depth.	50 Ft.
3. Determine Desired CFM/BU.	1/10Cfm/Bu.
4. Calculate Airflow (CFM/FT.^{2}) = Depth x 1 ft.^{2} x CFM/Bu. x .8 $\frac{Bu.}{Ft.^3}$	1 x 50 x 1/10 x .8=4
5. Read Chart Horizontally Along Line Representing Airflow to the appropriate Grain Curve.	Read along 4 to Corn
6. Read Down to Pressure Drop per ft. Depth	Down to .021
7. Multiply Pressure Drop x Total Depth for Static Pressure.	50 x .021 = 1.1
8. Add up to 50% for Grain Compaction.	1.1 x 1.5 = 1.7"S.P.

CHART "H"



CALCULATIONS	Example
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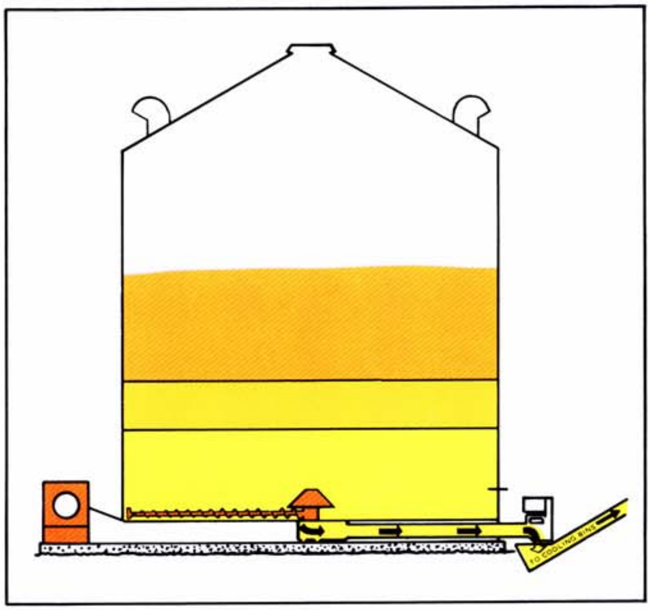
4. Calculate Airflow (CFM/FT.^{2}) = Depth x 1 ft.^{2} x CFM/Bu. x .8 $\frac{\text{Bu.}}{\text{Ft.}^3}$	1 x 50 x 1/10 x .8=4
5. Read Chart Horizontally Along Line Representing Airflow to the appropriate Grain Curve.	Read along 4 to Corn
6. Read Down to Pressure Drop per ft. Depth	Down to .021
7. Multiply Pressure Drop x Total Depth for Static Pressure.	50 x .021 = 1.1
8. **Add up to 50% for Grain Compaction.**	1.1 x 1.5 = 1.7"S.P.

CHAPTER 6

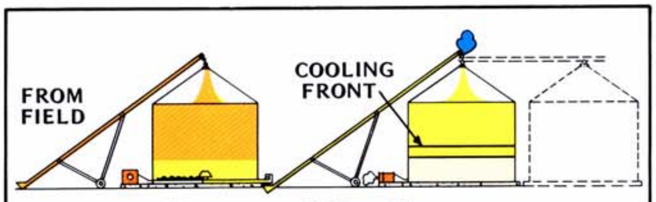
Engineering a Continuous, In-Bin Drying System

An In-Bin Continuous System consists of a grain bin equipped with a drying floor, a roof with adequate air outlets, a fan and heat unit and proper size transition capable of operating under relatively high static pressures, and a bottom unloading auger.



Heated air is forced up through the grain layer. This causes a drying front to form and move upward. As the front passes a temperature sensor, the unloader will turn on and begin to shear a layer of dry grain from the bottom of the bin. The grain, still warm, is transferred to a separate storage bin where it is cooled with aeration.

The unload auger usually operates intermittently because, as it passes beneath the temperature sensor, higher moisture grain falls down around the sensing bulb and causes the unloader to turn off.



Sequence of Handling

A number of continuous bin unloading systems are currently available. The systems work well if they are properly matched to your operation – specifically, the rate of harvest. In other words, the unloading equipment, bin and fan, must be properly sized so that satisfactory performance can be achieved under varying conditions.

The capacity of an in-bin, continuous operation will fluctuate with variations in the grain depth. As depth increases, static pressure against which the fan works also increases, and air output correspondingly decreases. Since air is the carrier of the heat energy needed to dry grain, heat energy input will decline along with reduced airflow, thus reducing drying capacity.

Since the capacity of an in-bin, continuous system fluctuates with the rate of loading, a targeted grain depth should be used upon which capacity may be estimated.

It is important that the variables affecting dryer performance be considered when making equipment selection. An improperly sized fan could easily reach a point of failure under deep layer, static pressure conditions.

Rule of Thumb

An efficient, in-bin continuous system is designed to operate at 160° F. Airflow should be 40 cfm/sq. ft. of floor space at 9' of grain depth when a 160° F. operating temperature is used. Static pressure at 18' of grain depth should not exceed the static pressure capability of the selected fan.

Using the parameters of design listed in the above "Rule of Thumb", you can determine the size of bin required to match your harvest rate.

When grain is sold, it is on the basis of weight, i.e., a bushel of corn weighs 56 lbs. A wet bushel, by volume, does not weigh 56 lbs. but, in fact, weighs considerably more. Referring to Chart "A" (page 3), you will note that a wet bushel of 25% corn weighs 63.09 lbs. To reduce a wet bushel of grain to a 56 lb. dry (15.5%) bushel, 7.09 lbs. of water must be removed. To dry down to 15% moisture, an additional .33 lbs. must be removed. Therefore, a total of 7.4 lbs. must be removed.

55.67 lbs. dry bu. x (100 - 15 dry bu. % ÷ 100 - 25 wet bu. %) = 63.09# wet bu.

The efficiency range of an in-bin continuous dryer has been measured at approximately 1400 BTU's, plus or minus 100 BTU's, depending upon the type of hybrid being dried, removing 1 lb. of water. This figure is used in our next calculation.

7.4 lbs. of H_2O x 1400 BTU's = 10,360 BTU's needed to dry one bushel (56# of 15% grain) in 60° ambient weather.

If 40 CFM are delivered per square foot at 160° F. operating temperature, a total of 4,400 BTU's per hour (drying input) are delivered. This calculation is made as follows:

CFM/Sq. Ft. x Heat Factor x Degree of Heat Rise between 60° F. and operating temperature = Btu/ Hr. drying input.

40 CFM/Sq. Ft. x 1.1 x 100° F. (60° F. to 160° F.) = 4400 Btu/Hr./Sq. Ft. of floor.

40 x 1.1 x 100 = 4,400

To find the capacity per square foot, simply divide the Drying Input by the BTU/hr. requirement.

4,400 ÷ 10,360 = .4247 dry bu./hr./sq. ft.

This calculation has already been made in Chart "K" (page 22) for various CFM and Bu./Hr. at a 9' depth.

If we select a 30' diameter tank for this example, we find that it has 706.8 sq. ft. of floor area. Capacity, therefore, is found by multiplying the sq. ft. times dry bushels per hour.

706.8 x .4247 = 300 dry bu./hr. (55.67# at 15% moisture)

The final step is to convert the dry bushels back to wet bushels so that field harvest rates can be compared. To do so, follow this sequence of calculations:

- 300 bu. x 55.67 lbs. = 16,701 lbs. dry grain.
- 16,701 lbs. x (100 - 15 ÷ 100 - 25) = 18,927.8 lbs. wet grain.
- 18,928.8 ÷ 56 = 337.98 so called wet bu./hr.

Now you can find how much grain can be handled in the drying system.

Rule of Thumb

Use 20 hours for estimating equipment operating time. This permits a 4-hour contingency for start-up delays, field equipment malfunction, etc.

337.98 wet bu./hr. x 20 hrs. = 6,759.6 bu./day

During the day, therefore, 6,759.6 bushels can be harvested without exceeding the drying capacity of the bin.

It is recommended, however, that a capacity be considered which is sufficient to dry most of the grain during daylight hours and take maximum advantage of solar heat. Nighttime drying is generally more costly since the drying air must be raised an additional 20° to 30° F. The difference in cost between nighttime and daytime operation could, in many cases, pay for the additional capacity needed for daytime only operation, and also provide a good return on the additional investment.

Chart "L" (page 22) provides the recommended size fan for each Behlen bin diameter, and also states the approximate drying capacity for each unit.

Designing The Bin For Uniform Airflow

Excessive air velocity is a frequently encountered design error. A basic law of design requires that air velocity entering the tank should not exceed 1750 feet per minute. The result of excessive air velocity can be seen in diagrams 1 and 2, below.

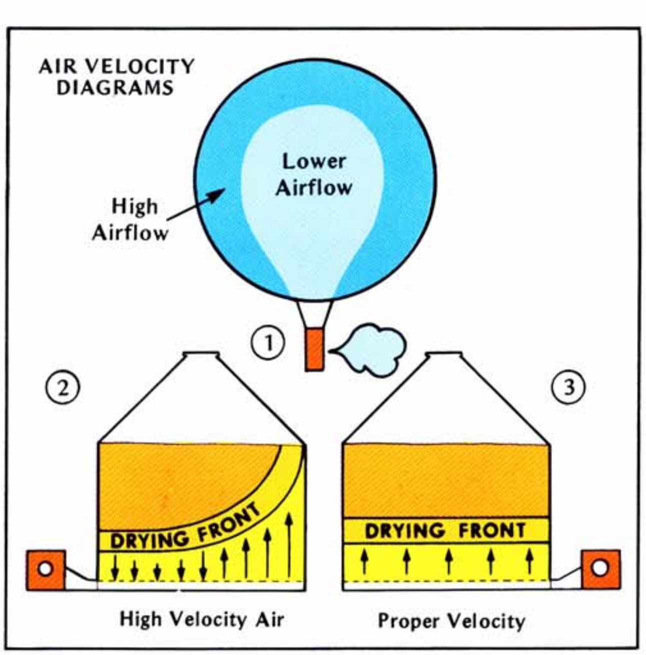


Diagram "1" (page 18) shows that a higher static pressure is created on the perimeter of the tank. Here the airflow through grain is much higher than at the center. This not only creates the problem of uneven and inefficient drying, but it can also place an extraordinary load on the mechanical equipment. As the unloading sweep proceeds around the bin, it eventually encounters a mass of considerably wetter grain. This places a heavy load on the equipment and could lead to failure.

Diagram "2" (page 18) presents the problem in section view. The affect of high static pressure at the back of the bin could cause a reverse airflow because of venturi action at the point of air entry.

The object of design should always be to achieve a uniformity of airflow across the drying floor (Diagram "3", page 18). This is achieved by providing an air entry transition of adequate size and a drying floor of proper height. To determine the correct dimension of the opening, follow this example:

Assume drying will take place in a 30' diameter bin (706.5 sq. ft.), and a fan is used which is capable of delivering an airflow of 40 cfm/sq. ft.

706.5 sq. ft. x 40 = 28,260 CFM
28,260 ÷ 1750 = 16.1 sq. ft. of bin wall opening.

If the drying floor is 18" high, the bin wall opening would correctly measure 10.7' wide x 1.5' high.

Total sq. ft. ÷ height = width of opening.
16.1 ÷ 1.5 = 10.7'

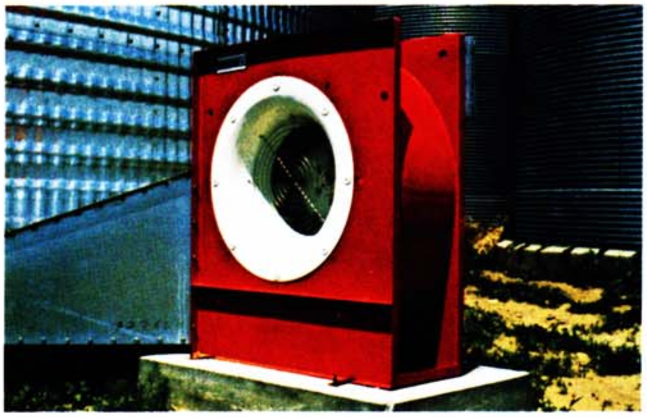
It is equally important to know the correct amount of roof opening to be provided.

Rule of Thumb **1.25 x sq. ft. of air inlet is required to avoid creating static pressure under the roof.**

Roof outlet design requires that an air velocity of 1400 feet per minute be used in the calculation.

28,260 ÷ 1,400 = 20.18 sq. ft. of roof opening (12 Roof Vents each with a 1.5 sq. ft. opening).

Choosing the Right Fan For Continuous In-Bin Drying



The rate of airflow in relationship to operating temperature is critical in this drying system. Choose your drying fan in the following manner:

Your objective should be to select a fan that provides an airflow of 40 CFM/sq. ft. of floor area through 9' of grain. Chart "I" helps solve part of the problem. At 40 CFM/sq. ft. at 9' of grain depth (corn), the fan will operate against 6" of static pressure.

The air-flow requirement for a 30' diameter bin would be 28,260 CFM at 6.0" of static pressure.

706.5 sq. ft. x 40 CFM/sq. ft. = 28,260 CFM

CAUTION: It is important to select a fan with sufficient airflow. An attempt to "get by" with insufficient airflow may cause moisture to be "dropped" in the upper layer of grain, thus reducing drying capacity. This happens because the air stream cools as it passes through the grain losing moisture carrying capacity.

Increasing heat does not solve the problem of slow drying. It will have an adverse affect. A temperature drop in the airstream will still occur, and since more moisture is removed from the bottom layer with the higher operating temperature, the problem will be worsened.

To maintain adequate moisture carrying capacity, the temperature of exhaust air should not be permitted to drop below 85° F. if possible. The exhaust air temperature can be controlled, to some degree, by grain depth; but if the operator chooses to use low H.P. and, consequently, low air flow, the operating temperature will probably have to be lowered to prevent excessive moisture from being transferred from the bottom to the top of the grain layer. Low air flow can also result if a maximum depth grain layer constantly exists. For example, if an operator harvested consistently at a rate considerably above the drying capacity of the system, a depth of 18' could quickly be reached. Airflow at that point would be at its lowest. Operating for short periods of time at this depth normally will not cause any problem, but if the operator chose to run at this depth for several days, a moisture buildup in the upper layers would be likely to occur, thus requiring a reduction in the operating temperature.

Operating temperature will determine largely the amount of water leaving the kernels in the drying zone at the bottom of the grain layer. Water is transferred from the kernel by a process called "osmosis". Heat is a catalyst to osmosis. High heat speeds up the process, and lowering the heat slows it down. More water, therefore, is released to the drying airstream when the operating temperature is high. So long as the exhaust airstream has sufficient water carrying capacity to remove the water from the bin, which is being released from the kernels in the drying zone, no problem will materialize. In the event that the exhaust air would not have the proper water carrying capacity, condensation would occur in the top grain layer, causing a moisture buildup at that point. As stated previously, lowering the operating temperature will slow down the release of water in the drying zone and will aid in eliminating the problem.

Because of the condensation factor, a continuous, in-bin drying system appears to be better suited to the central and southern corn belt.

Under proper operating procedures, there may still be times when the bin is filled to its maximum allowable depth for drying -- as much as 18'. The drying rate will, of course, slow down; but it is necessary to be sure that the fan will not "fail" under higher static conditions.

The performance of a fan under varying depths can be evaluated in the following manner:

Example No. 1:

Assume that equipment selection includes a 27' diameter tank (572.3 sq. ft. of floor area) and a 20 HP, 27" diameter centrifugal fan.

1. Place fan headings on a plain sheet of paper -- Static Pressure, CFM, CFM/Sq. Ft., & Grain Depth.
2. Under the heading of static pressure, list inches consecutively. 1" –2" –3" –4", etc.
3. Check the supplier's fan chart for performance under a given static pressure (for this example, see Chart "J", page 21).
4. Divide the CFM output of the fan, at a given static pressure, by square feet of floor area to determine the CFM/Sq. Ft. Record this amount for each inch of static pressure.
5. Refer now to Chart "I" (page 21). By first reading the CFM, and following across to the appropriate increment of static pressure, we then can find the depth of grain at which a particular condition occurs. Complete your chart in this manner. In this example, you will find that the fan will continue to perform adequately at a depth exceeding 20', but will not deliver the desired 40 CFM/square feet at 9' of depth. At 9', the airflow per square foot would be around 23 CFM . . . 17 CFM short of our requirement.

Static Pressure	CFM	CFM/Sq. Ft.	Grain Depth
1	19,500	34	2'
2	18,500	32.3	4'
3	17,500	30.5	6.5'
4	16,500	28.8	9.25'
5	15,500	27.0	13.5'
6	14,250	24.8	17.2'
7	13,000	22.7	20'+

Example No. 2:

Assume that a 27' diameter tank and a 40 HP, 30" fan is used.

Refer to Charts "I" and "J" in the same manner as shown above.

Static Pressure	CFM	CFM/Sq. Ft.	Grain Depth
1	28,500	44.1	–
2	27,500	43.4	2.5'
3	26,500	39.8	3.5'
4	25,250	37.6	5.0'
5	24,250	34.9	7.0'
6	22,750	39.7	9.0'
7	21,500	49.8	12.0'
8	20,000	48.1	14.5'
9	18,000	46.3	18'+

We can conclude that this fan will give us close to the required airflow at 9' of grain depth, and will not fail at a maximum fill of 18'.

CHART "I"

STATIC PRESSURE CHART

In Bin Continuous Bottom Unload Drying For Corn

CFM/Ft.^{2}	Feet of Grain Depth																	
	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'	14'	15'	16'	17'	18'	19'	20'
20	.7	.9	1.1	1.4	1.6	1.8	2.1	2.3	2.5	2.8	3.0	3.2	3.5	3.7	3.9	4.2	4.4	4.6
22	.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.2	4.5	4.8	5.1	5.4	5.7
24	.9	1.3	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.9	4.2	4.5	4.8	5.2	5.5	5.8	6.1	6.5
26	1.0	1.4	1.7	2.1	2.4	2.8	3.1	3.5	3.8	4.2	4.5	4.9	5.2	5.6	5.9	6.3	6.6	7.0
28	1.1	1.5	1.9	2.3	2.7	3.1	3.5	3.9	4.2	4.6	5.0	5.4	5.8	6.2	6.6	7.0	7.4	7.8
30	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.5	5.0	5.4	5.9	6.3	6.8	7.2	7.7	8.1	8.6	9.1
32	1.4	1.9	2.4	2.8	3.3	3.8	4.3	4.8	5.2	5.7	6.2	6.7	7.2	7.6	8.1	8.6	9.1	9.6
34	1.5	2.0	2.6	3.1	3.6	4.1	4.6	5.2	5.7	6.2	6.7	7.2	7.8	8.3	8.8	9.3	9.8	10.4
36	1.7	2.2	2.8	3.4	4.0	4.5	5.1	5.7	6.2	6.8	7.4	8.0	8.5	9.1	9.7	10.2	10.8	11.4
38	1.8	2.4	3.1	3.7	4.3	4.9	5.6	6.2	6.8	7.4	8.1	8.7	9.3	9.9	10.6	11.2	11.8	12.4
40	2.0	2.7	3.3	4.0	4.7	5.4	6.0	6.7	7.4	8.1	8.7	9.4	10.1	10.8	11.4	12.1	12.8	13.5
42	2.2	3.0	3.7	4.5	5.2	6.0	6.7	7.5	8.2	9.0	9.8	10.5	11.3	12.0	12.8	13.5	14.3	15.0
44	2.4	3.3	4.1	4.9	5.8	6.6	7.4	8.3	9.1	9.9	10.8	11.6	12.4	13.3	14.1	14.9	15.2	16.4
46	2.7	3.6	4.5	5.4	6.3	7.2	8.1	9.1	10.0	10.9	11.8	12.7	13.6	14.5	15.4	16.3	17.2	18.2
48	2.8	3.8	4.8	5.7	6.7	7.6	8.6	9.6	10.5	11.5	12.5	13.4	14.4	15.3	16.3	17.3	18.2	19.2
50	3.0	4.1	5.1	6.1	7.1	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.3	17.4	18.4	19.5	20.5
52	3.1	4.2	5.3	6.3	7.4	8.5	9.5	10.6	11.7	12.7	13.8	14.9	15.9	17.0	18.1	19.1	20.2	21.3
54	3.3	4.5	5.6	6.7	7.9	9.0	10.1	11.3	12.4	13.5	14.6	15.8	16.9	18.0	19.2	20.3	21.4	22.6
56	3.5	4.6	5.8	7.0	8.1	9.3	10.5	11.7	12.8	14.0	15.2	16.3	17.5	18.7	19.8	21.0	22.2	23.4
58	3.7	4.9	6.1	7.4	8.6	9.8	11.1	12.3	13.5	14.8	16.0	17.2	18.5	19.7	20.9	22.2	23.4	24.7
60	3.9	5.2	6.5	7.8	9.1	10.4	11.7	13.0	14.3	15.6	16.9	18.2	19.5	20.8	22.1	23.4	24.7	26.0

Inches Static Pressure

NOTE: Static pressure may vary slightly due to moisture content, amount of foreign material in the grain and the size of grain kernels. Figures given represent average pressures expected during normal operation.

CHART "J"

TYPICAL AIRFLOW FOR 1750 RPM CENTRIFUGAL FANS

Dia.	H.P.	Inches Static Pressure														
		1"	2"	3"	4"	5"	6"	7"	8"	9"	10"	11"	12"	13"	14"	15"
27"	10	9650	9250	8650	8250	7650	7000	6500	D							
27"	15	14500	13700	13000	12300	11350	10650	9850	D							
27"	20	19550	18550	17550	16550	15500	14250	13000	D							
30"	15	11900	11350	10850	10300	9900	9450	8900	8250	7550	D					
30"	20	15650	15100	14300	13750	13200	12500	11750	10950	10100	D					
30"	25	19875	18950	18050	17250	16550	15650	14800	13800	12650	D					
30"	30	23500	22500	21400	20600	19700	18800	17550	16450	15050	D					
30"	40	28600	27600	26600	25300	24300	22800	21550	20000	18050	D					
33"	25	16300	15700	15300	14800	14300	13650	13150	12450	11850	11050	10150	D			
33"	30	20150	19600	18800	17950	17200	16450	15650	14950	14050	13250	12400	D			
33"	40	26200	25250	24400	23650	22800	21850	20900	19900	18900	17550	16650	D			
33"	50	32650	31550	30450	29400	28300	27350	26350	25050	23800	22450	20800	D			
36"	30	16200	15950	15600	15250	14900	14450	14000	13500	13100	12600	12100	11500	10950	9950	D
36"	40	21650	21200	20900	20450	19950	19350	18900	18300	17650	17050	16250	15450	14650	13300	D
36"	50	27100	26600	26100	25525	24925	24250	23550	22850	22050	21250	20450	19450	18350	16650	D
36"	75	40650	39900	39150	38350	37350	36300	35300	34200	33050	31950	30550	29050	27350	24950	D

D = Fan has reached its maximum static pressure capability and airflow is declining rapidly.

The following charts will be a great aid in calculating dryer capacity and fan size of different diameter grain bins.

CHART "K"

CONTINUOUS IN BIN BOTTOM UNLOAD CAPACITY CALCULATION CHART

160° Operating Temperature

60° Ambient Temperature

CFM/FT.^{2}	Capacity* Dry Bu./Hr./Ft.^{2} 20%-15%	25%-15%	Inches Static Pressure at 9' Depth
20	.4489	.2123	2.1
25	.5612	.2654	3.0
30	.6734	.3185	4.0
35	.7857	.3716	4.9
40	.8979	.4247	6.0
45	1.0102	.4777	7.6
50	1.1224	.5308	9.2

*Efficiency calculated at 1400 BTU/# water removed.

CHART "M"

30' DIA. (706.8 SQ. FT.) 33" – 50 H.P. CENTRIFUGAL FAN

Static Pressure	CFM	CFM/Sq. Ft.	Ft. of Grain Depth
1	32650	46	Under
2	31550	44	Under
3	30450	43	3.5'
4	29400	41	5.5'
5	28300	40	7.5'
6	27350	39	9.5'
7	26350	37	11.5'
8	25050	35	13.5'
9	23800	34	17.5'
10	22450	32	20.5'
11	20800	29	Over 20

CHART "L"

MAXIMUM RECOMMENDED FAN SIZE IN BIN CONTINUOUS BOTTOM UNLOAD DRYING FOR CORN

Bin Dia.	Sq. Ft.	"S.P.	CFM/Ft.^{2} at 9 Ft. Depth	CFM	Recommended Centrifugal Fan Size
22'	380	6.1"	40'	15,000	30"–25 HP
26'-10¾"	567.8	6.1"	40'	22,750	30"–40 HP
34'-2¾"	919.4	6.1"	39.3'	36,200	36"–75 HP
41'-6¾"	1356.6	6.1"	35.6'	48,400	2 – 33"–50 HP
9 m (29'-6")	683.5	6.1"	35.4'	24,200	33"–50 HP
11 m (36')	1017.8	6.1"	42.8'	43,600	2 – 33"–40 HP

CAPACITY OF ABOVE SYSTEMS 25% TO 15% MOISTURE (CORN) OPERATING TEMP. 160° F.

Bin Dia.	Centrifugal Fan Size	CFM	BTU/Hr. 60° Ambient	Capacity** Drying 25% to 15% Wet bu	Dry bu
22'	30"–25 HP	15,600	1,716,000	188	166
26'-10¾"	30"–40 HP	22,750	2,475,000	271	239
34'-2¾"	36"–75 HP	36,200	3,982,000	435	384
41'-6¾"	2–33"–50 HP	48,400	5,324,000	583	514
9 m (29'-6")	33"–50 HP	24,200	2,662,000	291	257
11 m (36')	2–33"–40 HP	43,600	4,796,000	525	463

**Capacity will vary with clean grain and dirty grain as well as from one hybrid to another. Capacity will vary also with grain depth. Capacity shown is for a 9' depth with reasonably clean grain. Because of the many variables, any capacity shown is an approximation. Lower HP Fans can be used on any of the above dia. bins, but the capacity will be lowered accordingly. Caution must be used to avoid too low HP and hence too low airflow. Insufficient airflow will result in the transfer of water from the bottom to the top of the grain layer, unless the operating temperature is also reduced. Doing so reduces capacity considerably. Wet or dry bushels are equal to 56 lbs. of grain. Efficiency is calculated at 1400 BTU per pound of water removed in 60° ambient weather.

CHAPTER 7

Measuring Dryer Performance

The B.T.U. heat rating method

Investing in a grain dryer or bin drying system can be a hit or miss proposition --- but it does not have to be. It is possible to verify a manufacturer's advertised capacity claims before you buy.

Most manufacturers publish information on their product which includes column width, fan air flow at a given static pressure and the efficiency range of the system. The efficiency range of the system refers to the heat efficiency achieved in the removal of one pound of water, drying corn from an initial moisture content of 25.5% to a final kernel moisture content of 15.5%. The efficiency is expressed in numbers of BTU's to remove one pound of water in 60° F. ambient conditions. Efficiency of machines will range from about 1400 BTU's/Lb. water removed to as high as 3500 BTU's/Lb. water removed.

Rule of Thumb

The rule of thumb for estimating capacity, if the actual efficiency is unknown, is as follows:

Type Operating	= Probable Efficiency Range*
Port. Batch Dryer 180-200° Operating Temp.	= 2200 to 2300 BTU's
Column Continuous Dryer w/o Heat Saver	= 2500 to 2600 BTU's
Column Continuous Dryer w/Heat Saver	= 1500 to 1600 BTU's
Continuous Deep Layer in Bin Dryer	= 1400 to 1450 BTU's

***The grain column width or depth, the air-flow rate per bu. or sq. ft. and the general design of the different kinds of dryers will cause these efficiencies to change. There is no substitute for experience if accuracy in estimating is essential. The above figures are for rough estimating purposes only.**

With the required information in hand, the capacity of any dryer can be quickly computed using the "BTU rating method."

The first objective of this method is to establish the hourly drying input of the air stream. Here we are concerned only with the units of energy (BTU's) contained by the airstream between 60° F. and the operating temperature. After that amount of energy becomes known, it becomes a simple process to calculate hourly drying capacity. It should be noted that when using this method of calculating capacity, an ambient temperature of 60° F. is always assumed. Only when calculating fuel cost per bushel is the actual existing ambient temperature used.

To find the hourly BTU drying energy input, use the following procedure:

In this example, assume that a dryer fan and heat unit would deliver 35,000 CFM (cubic feet per minute) at an operating temperature of 200° F., then use this formula.

CFM x 1.1. x degrees of heat rise = BTU's/Hr. input

35,000 x 1.1. x 140 (60° F. to 200° F.) = 5,390,000 BTU's/Hr.

Having established the hourly BTU rate, refer next to the "Energy Requirement Chart," (page 25). This chart shows the BTU requirement for drying one bushel of corn from varying efficiency ranges. For example, if 25.5% moisture corn (63.5 lbs. per bushel wet) is dried to 15.5% moisture (56 lbs. per bushel dry), 7.5 lbs. of water must be removed per bushel. If a dryer operated in an efficiency range of 1,750 BTU's per pound of water removed, then 13,125 BTU's would be required to dry 1 bushel.

Example: 1,750 BTU's per pound of water removed x 7.5 lbs. = 13,125 BTU's.

If the dryer delivered 5,390,000 drying BTU's/Hr. as determined in our first calculations, the hourly drying capacity can be determined by dividing the hourly BTU's by the requirement per bushel.

Example: $\frac{5,390,000}{13,125}$ = 410.6 dry bushels per hour

We have established that the dryer in this example would have a capacity of 410.6 dry bushels per hour, drying from 25.5% moisture to 15.5% moisture. It is now possible to calculate wet bushels per hour using a formula in which a wet bushel equals 56 lbs. of wet grain. Farmers market their grain as wet bushels because some elevator operators still consider 56 lbs. to be a bushel of corn, regardless of moisture content. The elevator then discounts the price of corn to compensate for the expected grain shrink during drying. Because of this marketing method, we follow a procedure to calculate the so called "wet bushels."

$$\text{Dry bu.} \times \frac{100 - \text{dry percentage}}{100 - \text{wet percentage}} = \text{wet bushels}$$

$$410.6 \times \frac{84.5}{74.5} = 465.7$$

We can conclude that the dryer would have a capacity of 465.7 wet bushels per hour drying from 25.5% to 15.5% moisture.

The drying efficiency range of any dryer will vary from one season to another because of hybrid selection, rate of maturation and growing conditions. Efficiency will also vary somewhat depending upon the starting moisture content. Moisture is removed more easily from 30% moisture grain than from 20% moisture grain. This is because the rate of moisture migration from inside the kernel to the outer surface slows down as the grain dries. Experience has shown that variances up to 400 BTU's per pound of water can occur in a specific operation while drying from 25% down to 15% moisture. Because of the variables involved, it is appropriate that a dryer be rated in a "capacity range" rather than at a specific bushel per hour level.

When employing the "BTU rating method," it is sometimes necessary to draw from experience to choose the proper efficiency range for a given dryer. Typically, a wide column dryer may be slightly more efficient than a narrow column dryer, or a dryer with a low rate of airflow per bushel may be slightly more efficient than one with a relatively high rate of airflow. Even though these variables do exist, allowances can be made, and the "BTU rating method" can be used successfully to compare brands of equipment and their probable performance levels. If a dryer is overrated, this method of calculation can point out discrepancies very quickly. Discrepancies become even more evident when comparing several brands of dryers.

The chart on Page 25 shows the BTU/Bu. required to dry from various moisture contents to 15.5% moisture content at various efficiency ranges when utilizing the "BTU rating method" of calculating capacity.

Finding the Cost of Drying

When computing capacity, we use degrees of heat rise between 60° F. and the operating temperature -- regardless of what the existing ambient temperature may be.

When computing cost, we use the degrees of heat rise between the existing ambient temperature and the operating temperature.

For an example of estimating drying costs, assume the following:

Corn — Dried from 25% to 15% moisture
Existing Ambient — 40°
Operating Temperature — 160°
30 HP fan operating at 6" static pressure =
20,000 CFM
Dryer Operating Efficiency — 1400 BTU's
Electrical Cost — 4¢/KW
Propane Cost — 60¢/Gal.

Step No. 1: Calculate Capacity

A. CFM x Heat Factor x Degrees Heat Rise Fan 60° F. to 160° F. = Drying BTU's per bu.

20,000 x 1.1 x 100 = 2,200,000 BTU's/Hr.

B. Find the BTU's used per bushel to dry.

Note: BTU's per bushel is equal to the efficiency range of the dryer multiplied times the lbs. of water removed.

Drying from 25% to 15% moisture produces a shrink (# water removed) of 7.4 lbs. (Chart "A", page 3).

Lbs. shrink from 15.5% down to 15% + shrink from 25% to 15% = lbs. removed.

7.09 + .33 = 7.42 lbs. water

Lbs. shrink x efficiency range = BTU's used per bu.

7.4 x 1400 = 10,360 BTU's

C. Total drying BTU's per hr. ÷ BTU's per bu. = Dry Bu./Hr.

2,200,000 ÷ 10,360 = 212 Dry Bu./Hr.

D. Dry bushels x $\frac{100 - 15 \text{ wet } \%}{100 - 25 \text{ dry } \%}$ = Wet Bushels

$212 \times \frac{85}{75} = 240$ Wet Bu./Hr.

Step No. 2: Calculate Costs

A. Find the amount of propane fuel consumed. Propane contains approximately 91,500 BTU per gallon.

Total Air Flow x Heat Factor x Heat Rise From 40° to 160° F. ÷ BTU's per gallon of propane = Gal. per hr. consumed.

$$\frac{20{,}000 \times 1.1 \times 120}{91{,}500} = 28.85 \text{ gal./hr.}$$

B. Find the electrical requirement.

HP x KW Hrs./HP = KW/Hr.
(As a Rule of Thumb, use 1.34 KW Hrs/HP)

30 x 1.34 = 40.2 KW/Hr.

C. Assuming a propane cost of 60¢/gal. and an electrical cost of 4¢ per KW, total operating cost would be:

Propane = 28.85 x .60 =	$17.31
Electricity = 40.2 x .04 =	1.61
	$18.92

Cost per dry bushel = $18.92 ÷ 212 = 8.9¢
Cost per wet bushel = $18.92 ÷ 240 = 7.9¢

NOTE: This example has used a relatively low ambient temperature condition of 40° F. In computing the expected costs of operation in your area, it is suggested that the average temperature during the harvest period be used. If operating only during the day, use average daytime temperature -- thus reducing further the cost of drying.

ENERGY REQUIREMENT CHART
FOR B.T.U. RATING METHOD

Wet #/Bu.	% M.	#Shrink To 15.5% M.	Efficiency Range B.T.U./# Water Removed						
			1400	1500	1750	1850	2000	2300	2500
56.0	15.5	—	—	—	—	—	—	—	—
59.5	20.5	3.5	4,900	5250	6125	6475	7000	8050	8750
63.5	25.5	7.5	10500	11250	13125	13875	15000	17250	18750
68.1	30.5	12.1	16940	18150	21175	22385	24200	27830	30250
73.4	35.5	17.4	24360	26100	30450	32190	34800	40020	43500

CHAPTER 8

Reclaiming Heat from Continuous Dryers

The efficiency of continuous dryers has been substantially improved in recent years with the addition of heat reclaiming enclosures. A properly designed collector will produce excellent results. Improper placement, however, in certain climates, can cause exhaust moisture to recirculate and, in fact, reduce the efficiency of the dryer.

Diagrams No. 1 and 2 depict a single column of grain which is one foot wide and 10' high, similar to the Behlen 380 and 700 dryer columns. The numbers depict a typical operation. Even though only one column is shown, the figures represent the exhaust losses and possible energy savings for all four columns of a 700 dryer. Energy losses and possible savings for the 380 and 850 series dryers can be calculated by using the same savings percentages as are shown for the 700 unit.

How Much Heat is Normally Wasted?

Diagram No. 1 shows the loss of BTU's in the exhaust air stream when the ambient temperature is 60° F. and the operating temperature is 200° F., when drying corn from 25% to 15% moisture content. When conditions are average, the exhaust air temperature must reach 125° F. at the bottom of the heat cycle to dry the corn to 15% final kernal moisture content. This can vary somewhat from one hybrid corn to another, but 125° F. is a good average. If this temperature is reached at the bottom of the heat cycle, then the exhaust air temperatures shown in Diagram No. 1, for each one foot of sidewall, should also be fairly accurate. The column shown in Diagram No. 1 is 10' high and 1' thick, or equal to the Behlen 380 and 700 dryer columns. Even though the figures shown in Diagram No. 1 are representative of the Behlen 700 dryer, percentagewise, the same loss would occur in the 380 and 850 series machines. Note that 1,398,618 BTU's are exhausted in 60° F. ambient weather. This is 37.8% of the total energy being injected (3,696,000 BTU's).

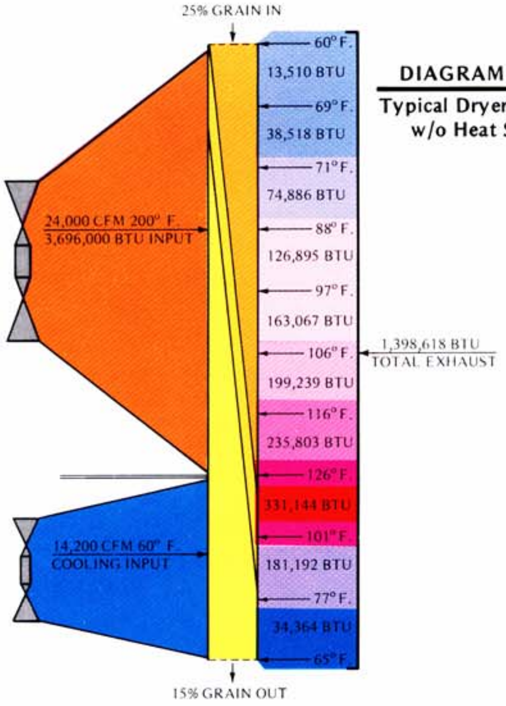


DIAGRAM NO. 1

Typical Dryer Column w/o Heat Saver

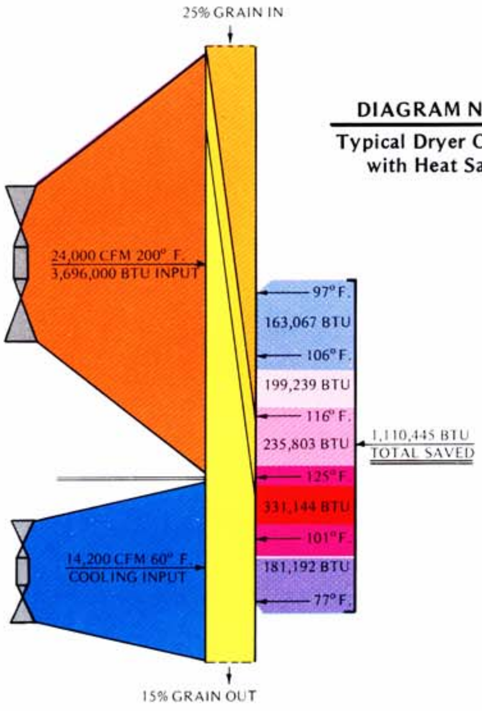


DIAGRAM NO. 2

Typical Dryer Column with Heat Saver

How Much Energy can be Saved?

Some energy must be used to heat the exhaust airstream to facilitate moisture removal. If too much of the exhaust air is "recirculated," then too much water would also be recirculated and the drying capacity of the dryer would be reduced.

Between 7% to 10% of the total energy input must be used to heat the exhaust airstream to give it sufficient water carrying capacity. It therefore seems possible to save or recirculate any of the exhaust which is approximately 100° F. or over. If a 5' high heat saver is designed to recirculate exhaust air from the bottom 3' of the heat cycle and the top 2' of the cooling cycle, then Diagram No. 2 shows the possible energy savings for 60° ambient weather conditions. Approximately 1,100,445 BTU's, or 30% of the total energy originally injected, can be saved. As the ambient temperature gets colder, the energy savings will increase. For example, in 40° F. ambient weather the savings would be approx. 35%.

What are the Economics of a Heat Saver?

If a Behlen 700 dryer is operated at 200° F. in 60° F. ambient weather, 3,696,000 BTU's are needed to heat the airstream, or 40.4 gallons of propane per hour would be consumed. If propane sold for 60¢ per gallon, then the hourly cost for heating fuel without a heat saver would be $24.24. If 1,100,445 BTU's/hr. can be saved by recirculating 5' of the exhaust, then the hourly propane consumption would be lowered from 40.2 gallons to 28.1 gallons per hour, and the cost would be lowered from $24.24 per hour to $16.86 per hour. This is a fuel savings of $7.38 per hour, or $103.32 for a 14-hour day – $1,446.48 for a 14-day season, which is a typical 45-50,000 bu. operation. Many users could pay for a heat saver in a single year; especially larger operators in cold climates where savings would be maximum.

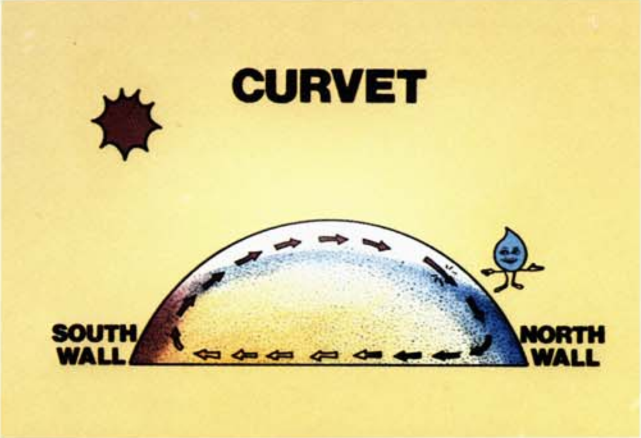
CHAPTER 9

Long-Term Storage

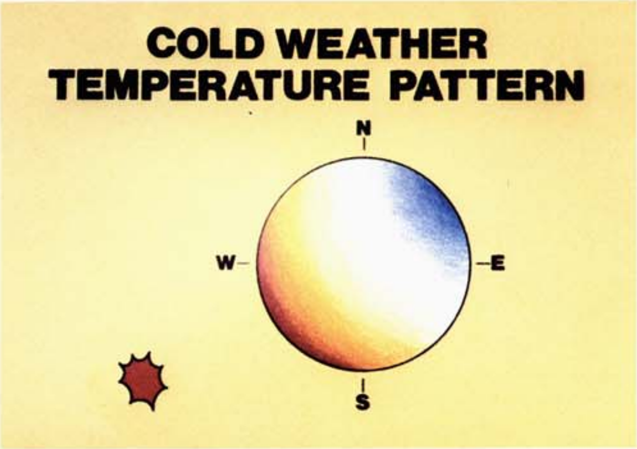
Playing it Safe with Aeration

Grain, only if dried to a very low moisture content, can be held without concern – and without aeration – for extended periods of time. The penalty imposed by overdrying grain, however, makes it advantageous to find an alternative solution to safe storage -- an aeration system.

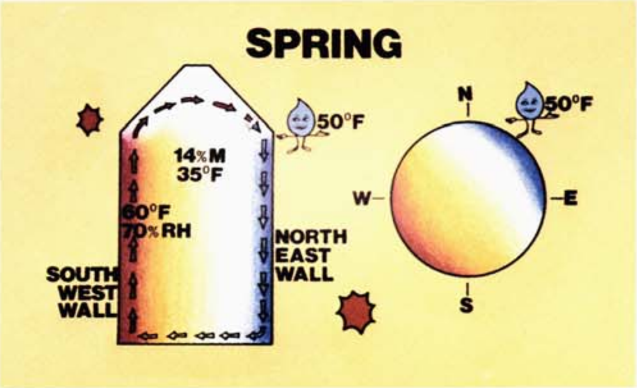
There is one villain in the age old story of grain spoilage --- temperature variation in the grain mass. Moisture migration, the movement of moisture from warm grain to cold grain is directly influenced by the temperature differential. Moisture migrates from warm grain to cold grain; and when it does, a number of unfavorable conditions can develop, including mold, deterioration and accelerated insect infestation.

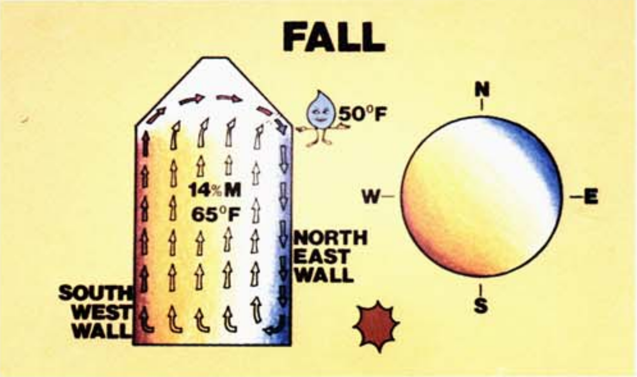


The solution to all these problems is to maintain a uniform temperature in the grain mass with aeration -- thereby minimizing moisture migration. The first illustration in the next column represents a typical condition.



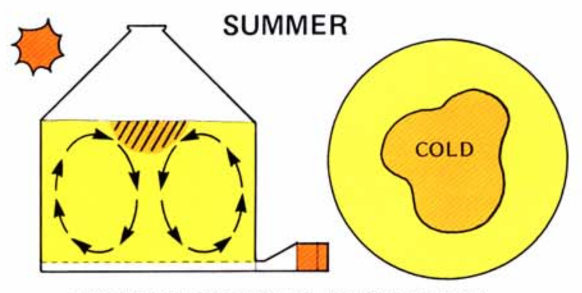
The Northeast side of the bin is shaded and cold. Conversely, the Southwest side of the bin warms in the sun. Cold air is heavier than warm air. The cold air falls, forcing the warmer, lighter air up, thereby creating convection currents in the grain. This is illustrated below.





Heated air rises on the sunward side of the bin. This heated air falls into equilibrium with the grain through which it passes, thereby absorbing moisture from the grain. As the warm, moist air enters the downdraft on the northern or cool side of the bin, condensation occurs, depositing unwanted moisture in the coldest area (usually the Northeast corner of the structure). If this process continues for a long enough period of time, considerable amounts of moisture can be deposited in a relatively small area. This is where mold and spoilage are likely to occur.

A similar condition can develop as grain continues to warm in the summer. In this situation, the center of the grain mass remains cool as the outer layer becomes warmed by the sun. The affect can be seen in the following illustration.



MOISTURE CARRYING AIR CURRENTS

Moisture carrying air currents move up the wall, and condensation occurs when the air reaches the cool grain at the center. Again, the result can be spoilage.

Eliminating Temperature Variation with Aeration

Aeration is not just a simple matter of attaching a small fan to a duct. As in any grain system, proper engineering is critical to good performance.

The first decision must deal with how quickly you wish to achieve a uniform temperature condition. The objective in aeration is to operate over a period of time each day when ambient temperatures are close to constant and the temperature adjustment in the bin is within allowable increments.

Example:

Assume that grain is to be warmed from a winter temperature of 35° F. up to a late spring temperature of 65° F. In this instance, temperature adjustment should be gradual. Approximately 10° F. maximum per adjustment in the grain temperature. The reason for gradual adjustment is to minimize condensation possibilities during the warming process. The initial ambient condition for aeration, therefore, should be around 45° F., advancing in increments of 10° F. as the temperature becomes uniform in the bin.

Winter adjustments are not as critical. Cold air will not deposit moisture in the warm grain while cooling. Nevertheless, effort should be made to operate at fairly consistent temperature levels.

CAUTION: It is not wise to aerate at temperatures below 35° F. Freezing the grain could lead to ice formation and restriction of airflow when warming the grain in spring.

An airflow of 1/2 CFM per bu. can cool or warm the grain in about 12 hours; 1/10 CFM (normal aeration air-flow rate) will require a minimum of 60 hours. Keep in mind that the ambient temperature may be proper for your purposes for only a few hours each day. If the temperature would be proper for six hours out of a 24-hour day, 10 days at six hours each would be required to change the temperature of the grain mass using 1/10 CFM/Bu. whereas only two days would be required with 1/2 CFM per bushel. Selecting the rate of airflow, therefore, becomes largely a personal time management decision. Even though air-flow rates under 1/10 CFM per bushel are feasible, we suggest that the operator consider 1/10 CFM per bushel as his minimum requirement.

Designing the System

Proper sizing of the system is important.

Rule of Thumb

One square foot of perforated duct surface should be provided for each 30 CFM delivered by the aeration fan.

If a flush floor aeration duct system is used, the maximum air handling capacity is simply determined by taking the square footage of perforated duct covering times the C.F.M. required.

Sq. Ft. perforated material x 30 CFM = allowable CFM fan capacity.

If round, perforated aeration ducts are laid on the concrete floor, only 80% of the duct surface can be utilized. The approximate 20% that points downward cannot be utilized efficiently, and should not be counted.

Example: 18" Duct 25' long.

(Duct diameter in inches x Pi ÷ 12) x (ft. length x 30 x 80%) = maximum allowable CFM.

(18" x 3.1416) ÷ 12) x (25 x 30 x .80) = 2827 CFM

Controlling Air Velocity

As in any bin drying system, the velocity of air in the duct or plenum should not exceed 1750 ft. per minute.

Rule of Thumb

One square foot of duct cross section is needed for each 1750 CFM of airflow produced by the fan.

Example for Round Duct 18" Diameter

(Inches radius x inches radius x Pi) ÷ 144 x 1750 = maximum allowable CFM

(9 x 9 x 3.1416) ÷ 144 x 1750 = 3093 CFM

An example for computing the proper cross section of a flush-floor duct system is as follows:

Assume that the bin to be aerated is 30' in diameter with a 30' high eave, and has an approximate capacity of 17,000 bushels when filled to the eave. The fan selected for aeration would produce an airflow of 1/4 CFM per bushel. Total fan output, therefore, would be 4250 CFM.

.25 CFM x 17,000 bushels = 4250 CFM

4250 CFM ÷ 1750 FPM = 2.4 sq. ft.

If a single air entry were used, the cross section of the duct would have to be 2.4 sq. ft. This may be overly large for most systems, and two entries might be preferable. In this event, the cross section of each entry would be 1.2 sq. ft.

Next, convert the cross section to inches.

1.2 sq. ft. x 144 sq. in./sq. ft. = 172.8 sq. in.

If an eight-inch deep trench is formed in the concrete, a width of approximately 22" will be required.

172.8" ÷ 8" deep = 21.6" wide (round to 22")

Two inches should be added to the width to allow for duct supports, thus creating a total width of 24".

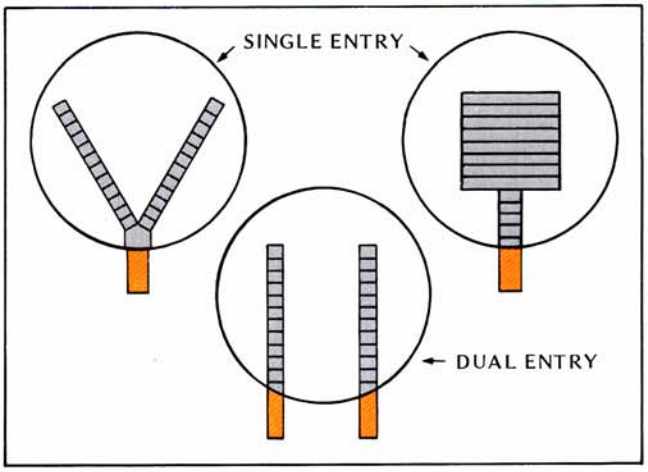
The final step is to determine the length of each duct. With an air-flow requirement of 2125 CFM for each duct (4250 CFM ÷ 2), the total square footage is found dividing by the original 30 CFM/Sq. Ft. requirement.

2125 CFM ÷ 30 CFM/Sq. Ft. = 71 Sq. Ft. minimum of perforated floor area per duct.

Since each running foot of duct would cover two square feet of the trench, total required length would be 35.5'.

71 sq. ft ÷ 2 sq. ft. = 35.5' long

Depending upon length of duct, installation may be accomplished in various configurations as shown below.



Glossary of Terms

1. **Aeration:** The moving of air through stored grain at low air-flow rates to equalize the temperature of the grain mass.
2. **Air Velocity:** The speed of air flow in feet per minute through a given (cross-section) area. Air velocities that exceed 1,500 to 1,750 cfm per square foot of duct area are not desirable because of resulting inefficiencies.
3. **Ambient Temperature:** Outside air or atmospheric temperature.
4. **B.T.U. (British Thermal Unit):** A measure of quantity of heat. (One B.T.U. will raise the temperature of one pound of water 1° F.)
5. **B.T.U./Hr.:** A common standard by which a heating unit is rated. (A heating unit is usually rated at its maximum output.)
6. **Bushels:** One bushel equals 1¼ cu. ft. The generally accepted weights in pounds per one bushel of grain are as follows:

Shelled Corn	56	Grain Sorghum	56 & 50	Oats	32
Soy Beans	60	Wheat	60	Barley	48

7. **C.F.M. (cubic feet per minute):** A common measure of a quantity of air movement. Fans are rated at so many C.F.M. at a given R.P.M. working against a determined static pressure.
8. **Cooling Cycle:** The period of time that grain in a dryer is subject to air movement by the fan without the burner being lighted. Grain should be cooled as close as possible to ambient temperature.
9. **Drying Cycle:** The period of time that grain in a dryer is subjected to the movement of heated air.
10. **Drying Front:** The high moisture edge or surface of the drying zone. That layer of grain in which most of the drying is occuring at any given time.
11. **Drying Zone:** A layer of grain in which moisture content is being reduced at any given time during the drying process.
12. **Equilibrium:** See Point of Equilibrium.
13. **Exhaust Air:** The air leaving the grain after having absorbed as much moisture as possible.
14. **Fan Curve:** The curve on a graph that represents fan output at various static pressures.
15. **Heat of Vaporization of Water:** 1075 BTU's are required to evaporate one pound of free water.
16. **L.P. Gas:** A mixture of various petroleum products usually consisting of propane and butane (normally stored and transported as a liquid under pressure).

Factor	Propane	Butane
Weight per gallon (lbs.)	4.24	4.84
BTU per pound	21.560	21.180
BTU per gallon	91.500	102.600

17. **Manometer:** A "U" shaped tube (usually glass) used to measure static pressures.
18. **Plenum:** The pressure chamber through which the drying air passes just prior to entering the product being dried.
19. **Point of Equilibrium:** Grain and the surrounding air are said to be in equilibrium when conditions are such that the vapor pressure of the air is equal to the vapor pressure of the grain. Under these conditions no transfer of moisture will take place.
20. **psi:** Pounds per square inch. A unit to measure the intensity of pressure.
21. **Relative Humidity:** A measure of the moisture content of the air relative to fully saturated air.
22. **R.P.M. (Revolutions Per Minute):** The common method of expressing speed of rotating parts.
23. **Static Pressure:** A measure of the air pressure in the plenum chamber. (Usually expressed in inches of water column.) Small kernel grains (such as wheat and milo) and trash grains pack close together and offer greater resistance to air movement, thus causing higher static pressures to develop.
24. **Supplemental Heat:** Intermittent addition of heat to the air stream. Used to lower relative humidity to the desired level for drying.
25. **Temperature Rise:** The difference between ambient temperature and plenum temperature is referred to as the temperature rise.
26. **Specific Heat:** The amount of heat energy required to raise one pound of matter one degree F.
27. **Specific Heat of Air:** 24 BTU's are required to raise one pound of air one degree F. If 13.213 ft.^{3} of air weighs one pound, then .018 BTU's would be required to raise one cubic foot of air one degree . . . 24 ÷ 13.213 = .018.
28. **Specific Heat of Corn:** .5 BTU's when corn is at 25% moisture content.

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